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Site descriptive modelling
SDM site

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Preface

The Swedish Nuclear Fuel and Waste Management Company (SKB) is undertaking 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. The analysis and modelling of data from the site investigations provide a foundation for the development of an integrated, multidisciplinary Site Descriptive Model (SDM) for each of the two sites. A site descriptive model constitutes a description of the site and its regional setting, covering the current state of the geosphere and the biosphere, as well as those natural processes that affect or have affected their long-term development. The site descriptions should serve the needs of both Repository Engineering and Safety Assessment with respect to repository layout and construction, and its long-term performance. They should also provide a basis for the Environmental Impact Assessment. The surface system consists of a number of disciplines that have worked together within the project group SurfaceNet. The disciplines involved in the description are:

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

The focus of the description, besides a general description of site conditions, has been to support and answer a few general questions, such as:

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

Previous versions of these site descriptions have been published for both Forsmark and Laxemar-Simpevarp. The latest version of the overall concluding site description, SDM-Site, is found in the SDM reports, Site description of Forsmark at completion of the site investigation phase. SDM-Site Forsmark. SKB TR-08-05; Site description of Laxemar at completion of the site investigation phase. SDM-Site Laxemar. SKB TR-09-01. Further, a more comprehensive overall surface system description of the Forsmark and Laxemar-Simpevarp areas can be found in the two Surface system reports Lindborg T (ed.) 2008. Surface System Forsmark, Site descriptive modelling, SDM-Site Forsmark, SKB R-08-11. Söderbäck B, Lindborg T (ed.) 2009. Surface System Laxemar-Simpevarp, Site descriptive modelling, SDM-Site Laxemar-Simpevarp, SKB R-09-01.

The present report comprises an integrated description of the terrestrial ecosystem and will provide the necessary information to evaluate the two sites from an ecosystem perspective.

Tobias Lindborg
Project leader, SurfaceNet

Summary

Generally, elements are transported and accumulated in ecosystems to a different extent, depending on the properties of the element and the context it is exposed to. This report describes the terrestrial ecosystems in the Forsmark and Laxemar-Simpevarp areas by summarizing ecological data and data from disciplines such as hydrology, quaternary geology and chemistry. The description therefore includes a number of different processes that drive element fluxes in the ecosystems, such as net primary production, heterotrophic respiration, transpiration, and horizontal transport from land to streams and lakes. Moreover, the human appropriation of the landscape is described with regard to land use and potential and actual utilization of food resources both today and in a historical perspective.

Wetlands occur frequently in Forsmark and cover 10–20% of the area, whereas wetlands are less frequent in the Laxemar-Simpevarp area, covering only approximately 3% of the main catchment. The main portion consists of open wetlands. A major difference between the sites is the great calcareous influence on the wetlands in Forsmark, resulting in a rich fen vegetation characteristic of this region. The Laxemar-Simpevarp wetlands have a lower pH and are often dominated by *sphagnum* species. The agriculture land is a major provider of food for humans and is less abundant in the Forsmark area (4%) compared with the Laxemar-Simpevarp area (8%). Production in both areas is dominated by fodder and grass for domestic animals and only around 10% of the agricultural land is used for crops. Clayey till dominates in Forsmark, whereas gyttja clay dominates in the Laxemar-Simpevarp area. At the latter site, arable land is situated in valleys that in many cases are former wetlands, which can be seen as a thin peat layer in many of the arable land areas. Forest land covers 73% and 86% of the area in Forsmark and Laxemar-Simpevarp, respectively, and consists mainly of coniferous forests. The forests feature moister conditions in Forsmark, whereas drier areas and outcrops are more abundant in the Laxemar-Simpevarp area. The calcareous soil provides nutrient-rich conditions, making herbs and broad-leaved grasses abundant in the field layer of the forests of Forsmark. The results of both modelling and the national forest inventory in the region suggest that a number of ecosystem properties are of a similar magnitude such as Net Primary Production (NPP), biomass etc. Generally, the higher latitude of Forsmark would suggest a lower NPP. However, these properties are also dependent on factors such as nutrients, moisture and the age of the forest. The later factor is mainly affected by the forestry management practices applied in the two areas.

Extensive inventories of mammals conclude that the moose populations are of similar size, while roe deer have higher densities in Forsmark. Lynx have recently become established in the Forsmark area, whereas red deer, fallow deer and wild boar have become established in the Laxemar-Simpevarp area. Domestic animals have a markedly higher biomass per unit area than free-living animals. However, their spatial distribution is very limited and concentrated to agricultural areas (area for seed production excluded), which are sparse in both the Forsmark and Laxemar-Simpevarp areas.

The yields of six different species of berries and fungi (0.091 gC m^{-2} y^{-1}) were estimated for both sites. Present-day picking and consumption of berries is less than 5% of the yield, but may vary depending on different circumstances. Hunting of moose and roe deer is on similar scale at both sites, approximately 0.5 and 2 individuals km^{-2} for roe deer and moose, respectively.

A conceptual description of terrestrial ecosystems is presented. It consists primarily of descriptions of pools and fluxes of organic matter, but also serves as a conceptual approach for describing pools and fluxes of other elements present in the ecosystems, which are explored from a mass balance perspective.

Detailed descriptions of pools and fluxes of carbon for three localities at each site were undertaken with the aim of describing some dominant and poorly described ecosystems. The vegetation types were two Norway spruce forests of different ages, one alder swamp forest, one oak forest, one alder shore forest and one planted Norway spruce forest on previously drained wetland. Generally, the estimated pools and fluxes from the six localities in Forsmark and Simpevarp were in agreement with similar studies, where available. NPP was estimated to be between 360 and 736 gC m^{-2} y^{-1} for the different forest types at the two sites, where the alder shore forest in the Laxemar-Simpevarp area had the lowest NPP and the Norway spruce forest on drained organic soils in the Laxemar-Simpevarp area had the highest NPP. All sites seem to have been carbon sinks during the period of the measurements (142–311 Cm^{-2} y^{-1}), except for the oak forest and the alder shore forest, which were close to zero. Nevertheless, the estimates presented here, both single estimates of pools and fluxes and ecosystem emergent properties, are well within expected ranges.

A dynamic vegetation model, LPJ-GUESS, was used to estimate pools and fluxes of carbon for 12 different vegetations types at each site using the local climate as the driving variable. These results were compared with site estimates and literature data. Values were in the upper range of boreal forests but still not unrealistic in comparison with field data and literature values. The results from this model were also combined with remote sensing data in order to study the variation in NPP of the tree layer. Moreover, the temporal dynamics of a number of ecosystem properties were studied for a forest at both sites during a period of 400 years. Data were also extracted for a 100-year period in order to obtain the mean values of e.g. NPP, biomass and soil organic carbon accumulation, which would approximate a forest cycle under forestry management.

Carbon pools and fluxes, which are used as a proxy for organic matter, were described on the scale of the catchment. The rationale for using the catchment scale is that transport of elements is mediated by water and the catchment will set the boundary for further transport and accumulation. The carbon estimates were based on a combination of field and model estimates of pools and fluxes across a landscape mosaic of different vegetation types and management regimes using a geographical information system (GIS). This modelling exercise showed a net biomass gain of 139 gC m^{-2} y^{-1} and a net carbon accumulation of 79 gC m^{-2} y^{-1} in the SOC pool summed over all catchments for Forsmark. The corresponding figures for Laxemar-Simpevarp were a net biomass loss of –66 gC m^{-2} y^{-1} and an accumulation of 174 gC m^{-2} y^{-1} in the soil organic carbon pool. The flux of carbon from autotrophs to herbivores is close to 1% of the autotrophic production in Forsmark but nearly 5% in Laxemar-Simpevarp. This difference is due to the higher abundance of livestock in Laxemar-Simpevarp, and if these are excluded the consumption is close to 0.5% at both sites. The most important herbivore as regards consumption and production (except for livestock) is roe deer, closely followed by moose in Forsmark, while the opposite is true in Laxemar-Simpevarp. Some vegetation types are regarded as more important for long term accumulation of matter. For example, vegetation types periodically inundated by water have a higher accumulation of matter, leading to peat formation, than other terrestrial vegetation types. These vegetation types cover a larger area in Forsmark than in Laxemar-Simpevarp. Similarly, some catchments are more important than others with regard to accumulation of organic matter, depending on their composition. Catchments dominated by younger forests will have a higher potential for assimilating bioavailable radionuclides today than catchments with a large proportion of clear-cuts.

Human appropriation of the landscape was described and analyzed using three different cases: a regional generic case, a self-sustainable case and a case where all potential arable land was used for agriculture. The three case studies of human utilization of food production (crops, meat and milk) showed that production today is far less than the potential production with regard to organic matter. Estimated food production in Forsmark based on regional statistics was only 0.8% of the potential production arable land is only used for growing crops. The corresponding figure for Laxemar-Simpevarp was 15%, suggesting a higher utilization of the potential resources in that area.

The distribution of 62 different elements among the four compartments mineral soil, humus layer, producers and consumers showed consistent patterns between the sites. Most of the elements found in high content in the vegetation were nutrients. The nutrients are found in the non-metals and metals groups. Many of the other elements found in the vegetation behave analogously to nutrients and are therefore found in the same places. Other elements seem to be restricted to the fine roots, such as U, Cd and Hg. Generally, small amounts were found in the consumer pool. The mass balances of four elements illustrated some different patterns, where the water-soluble micronutrient iodine was to a large extent incorporated into the vegetation and transported further downstream into the lakes. The distribution of the macronutrient phosphorus was similar, but only a small quantity was transported from the terrestrial areas. The mass balance suggested a large retention of phosphorus at the catchment level, of which a large fraction was retained in the vegetation. Thorium and uranium had their largest pools in the mineral soil and to a lesser extent in the humus layer. They showed a less mobile pattern with low amounts found in the vegetation or transported downstream.

Vegetation succession and long-term evolution are important aspects, due to the shoreline displacement that has strongly affected both Forsmark and Laxemar-Simpevarp since the last deglaciation and is still causing a relatively predictable change in the abiotic environment, and the long-term assessment of the safety for a nuclear waste disposal facility.

Contents

1 Introduction

This report is a compilation of previously reported data and new data aimed at describing the terrestrial ecosystems at Forsmark and Laxemar-Simpevarp, the two potential sites for a deep repository of spent nuclear fuel. Several authors have provided the original texts for this report:

Sofia Miliander, Vattenfall Power Consultants. Chapter 4, the sections describing fauna and land use for agriculture land and forests. Chapter 8, calculations for fauna and human consumption.

Lotta Rubio Lind, SKB. Chapter 4, the sections describing biomass and production estimates of birds and, berry and fungi yield.

Karolina Stark, Department of Systems Ecology, Stockholm University. Sections describing wetlands, 4.1.1 and 10.4.1.

Torbern Tagesson, Department of Physical Geography and Ecosystems Analysis, Lund University. Chapter 7.

Johan Stendahl, Department of Forest Soils, SLU Uppsala. Section 10.2.

Kent Werner, Emptec, and Per-Olof Johansson, Artesia Grundvattenkonsult AB. Sections describing climate and surface hydrology.

Gustav Sohlenius and Anna Hedenström, SGU. Sections describing Quaternary geology in Chapter 3, 4 and 10.

Anders Löfgren, EcoAnalytica. Chapter 1–2, 5, 6, 8, 9, 11, parts describing vegetation in Chapter 3, 4 and 10. Coordinating and editing text.

Many improvements on earlier versions of this report were suggested by: Regina Lindborg (Department of Systems Ecology, Stockholm University), Tryggve Persson (Department of Ecology, SLU Uppsala, Chapters 5–8), Angelica Lorentzon (SKB, Chapters 1–5 and 10), Björn Söderbäck (SKB, Chapter 10 and 11), Johan Truvé (Svensk Naturförvaltning AB, Section 4.2). Eva Andersson , Sara Nordén, Karin Aquilonius, Ulrik Kautsky and Tobias Lindborg have contributed with comments and in discussions on the report content.

Malin Andrée (SWECO position AB) helped with GIS-related support and Linda Falk (SWECO position AB) has contributed a number of GIS-based pictures. Richard Nord has edited the English language.

The opinions expressed in this report do not necessary comply with those of the reviewers. Pictures have been taken by the editor if not otherwise stated.

1.1 Background

Radioactive waste from nuclear power plants in Sweden is managed by the Swedish Nuclear Fuel and Waste Management Co, SKB. Within SKB's programme for the management of spent nuclear fuel, an interim storage facility and a transportation system are in operation today (October 2008). An application to build a final repository will be submitted in the middle of 2010 according to current plans. In the proposed method for spent fuel disposal, copper canisters with a cast iron insert containing spent nuclear fuel are surrounded by bentonite clay and deposited at a depth of approximately 500 m in saturated granitic rock. Around 9,000 tonnes of spent nuclear fuel is forecast to be generated by the Swedish nuclear power programme, equivalent to roughly 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) (Figure 1-2).

One critical task is to characterize long-term safety for a deep repository. To this end a safety report will be produced in order to support the application in 2010. A preliminary version of such a safety report is the SR-Can report /SKB 2006a/. A similar, updated and extended report will be available in time for the application in 2010. Before this, an extensive report describing each site will be available, i.e. a site descriptive model. Preliminary versions of these reports were published in 2005 and 2006 /SKB 2005 and SKB 2006b/. The coming reports will summarize other more detailed background reports in which terrestrial, limnic and marine ecosystems, surface hydrology and other surface system disciplines are described (Figures 1-1 and 2-1). This report is one of those background reports and describes the input data and methodology relating to the site description of the terrestrial ecosystems in the Forsmark and Laxemar-Simpevarp areas. Similar reports describing the marine ecosystems /Wijnbladh et al. 2008/ and the limnic ecosystems /Nordén et al. 2008/ have also been published. These three ecosystem reports will be published in two editions. The additions to the first editions will include extensive chapters describing future conditions on the site, the radionuclide models and their parameterization.

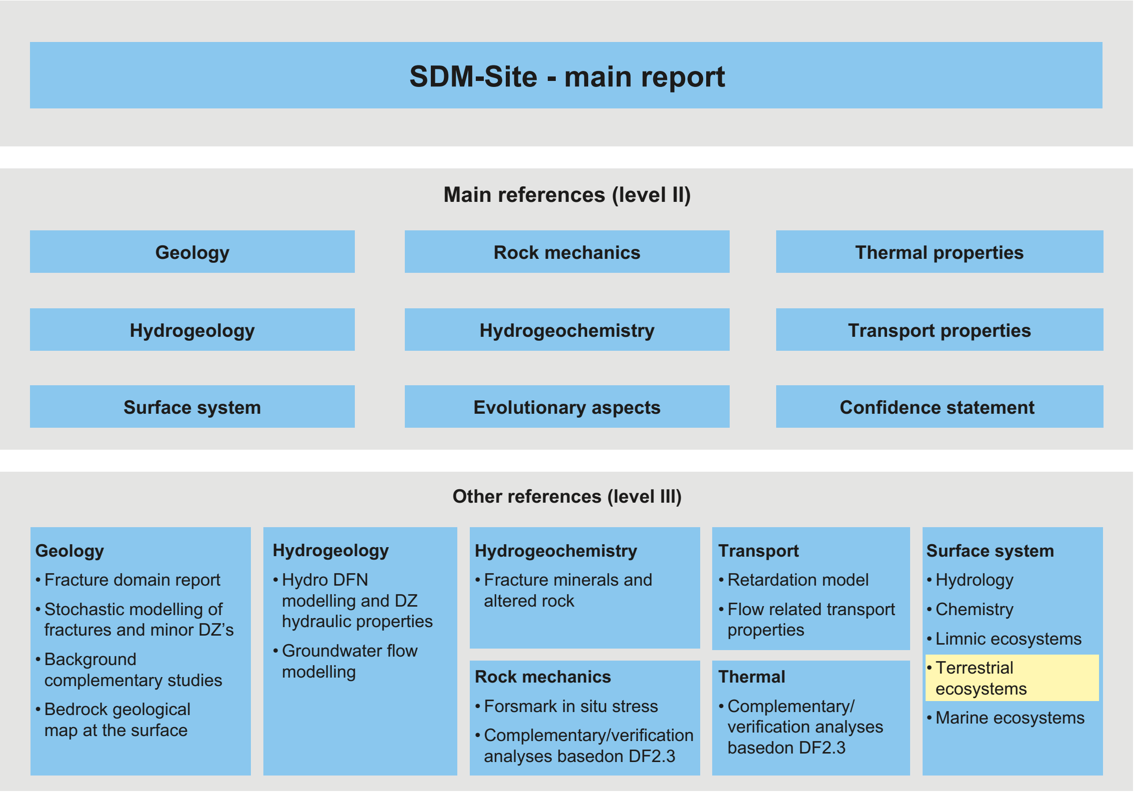

Figure 1-1. *Structure of the reports produced as a basis for the Site Descriptive Models and the Safety Report.*

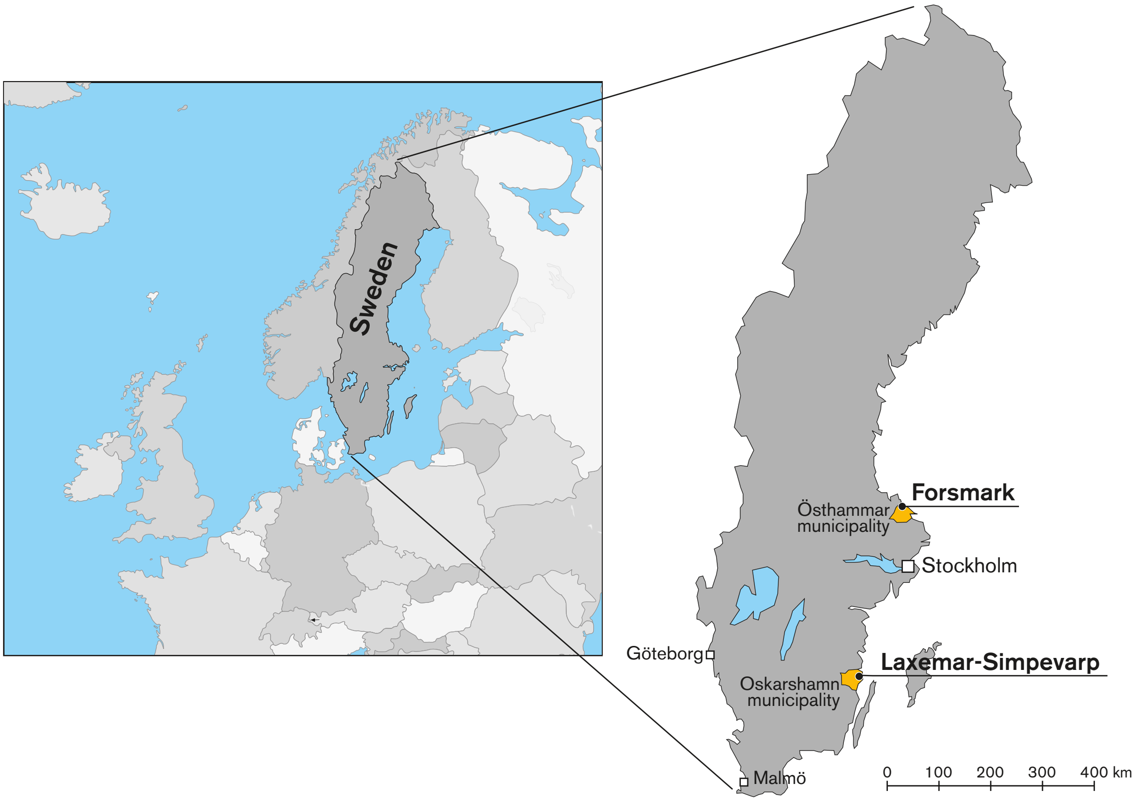

***Figure 1-2.** Location of the Forsmark and Simpevarp investigation areas in Sweden.*

1.2 Aims

The overall objective of this report is to describe the terrestrial ecosystem at the two sites Forsmark and Laxemar-Simpevarp. It summarizes the site investigations that are presented in more detail in separate reports and also presents descriptions and estimates of data not presented elsewhere. The intention is firstly to give the initiated reader a coherent description of the terrestrial ecosystems at the site. Secondly, the data are used, along with other information, to provide rough descriptions of pools and fluxes in those ecosystems of organic matter, water and other elements. Such descriptions will be used in the Safety Assessment to better understand and predict the fate of radionuclides in the landscape. The major outputs of this first edition of the report can be summarized as:

- A description of the current terrestrial ecosystems.
- A compilation and overview (covering ecological aspects) of the different studies conducted during the site investigations.
- Descriptive ecosystem models of pools and fluxes of carbon on a local and a regional scale.
- A description of pools and fluxes of a large number of different elements on a regional scale.

1.3 Geographical settings

The two potential repository sites, Forsmark and Laxemar-Simpevarp, are located on the Swedish east coast in the drainage area of the Baltic Sea, Figure 1-2. Detailed maps including geographical names, roads, model areas etc. are found in Appendix 1 (Forsmark area) and Appendix 2 (Laxemar-Simpevarp area).

Sweden generally has a maritime climate, distinguished by cool summers and mild winters. However, further north in Sweden the climate tends to be more continental with a greater difference between summer and winter. Since the Forsmark area is located north of the Laxemar-Simpevarp area, the climate tends to be more continental in Forsmark than in Laxemar-Simpevarp. The mean annual air temperature is also somewhat lower in the Forsmark area. Both sites are located in the boreonemoral vegetation zone, dominated by Scots pine (*Pinus sylvestris*) and Norway spruce (*Picea abies*).

2 This report

This section serves both as a summary and a guide for the reader, while putting the report in a broader context. The objectives are also presented in this section, but perhaps more importantly, it describes 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 the radionuclides and the exposure of humans and biota to them. This report describes the terrestrial ecosystems in the Forsmark and Laxemar-Simpevarp areas by summarizing and performing cross-disciplinary analyses of data from a large number of reports produced during the site investigations, Figure 2-1. The report describes the terrestrial landscape, divided here into the three main categories forests, wetlands and agriculture land, by identifying properties that are important for element accumulation and transport.

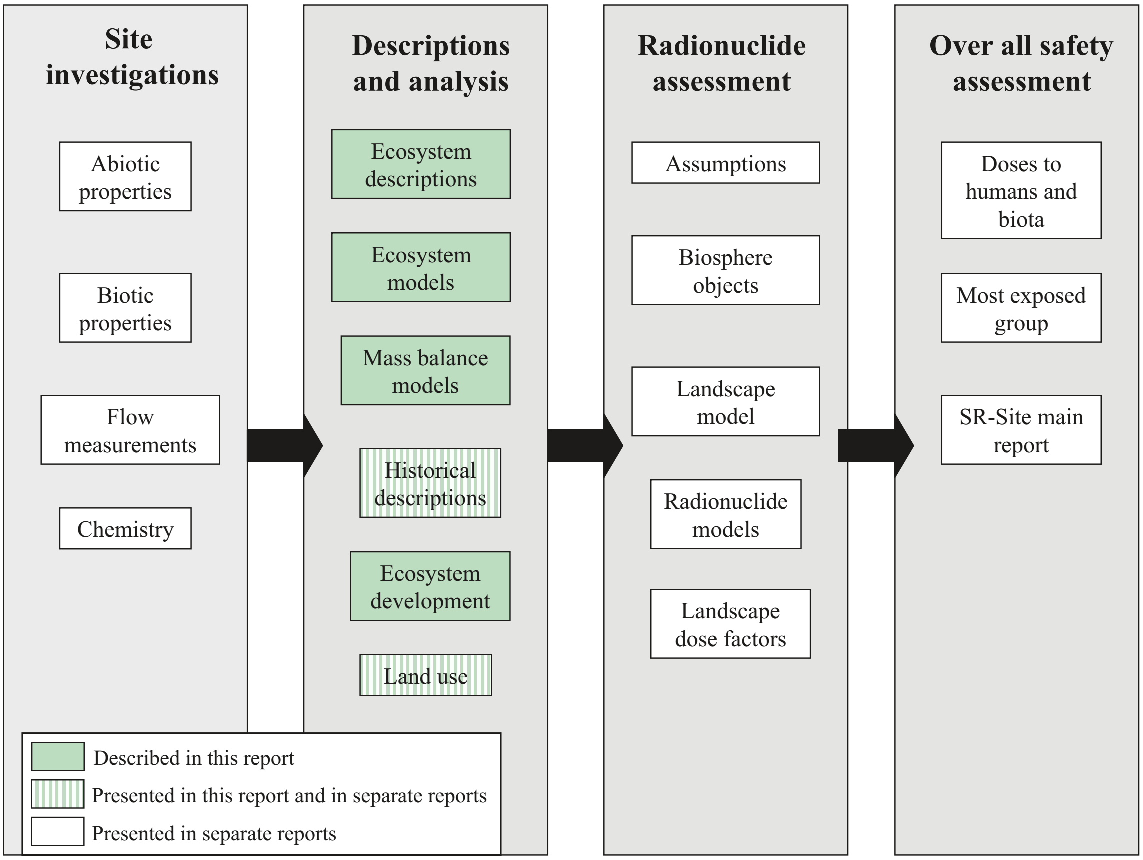

***Figure 2-1.** A schematic diagram showing how different results are used in this report and how these results feed into biosphere dose modelling and safety assessment.*

2.2 Report contents

Elements are transported and accumulated in the biosphere to a different extent, depending on the properties of the element and the context it is exposed to. This report describes the biotic and abiotic context at the sites and describes conceptually the potential transport and accumulation of elements in the terrestrial ecosystems and in the landscape (Figure 2-2). The description integrates knowledge from ecology as well as hydrology, quaternary geology and chemistry, and includes a number of different processes that drive element fluxes in the ecosystems, such as net primary production, heterotrophic respiration, weathering, leaching etc. The model is explored using both a detailed approach involving local measurement of fine-scale quantities and a broader approach with more coarse-scale quantities such as climate to elaborate on the potential pools and fluxes of organic matter. Moreover, within the timespan of the safety assessment, several thousand years, the landscape will be reshaped, largely due to ongoing and predicted shoreline displacement in the area. Due to these processes, marine areas will become lakes that in turn will become wetlands and other terrestrial ecosystems, including agricultural areas. Elements accumulated in the limnic ecosystems will therefore subsequently form a part of the terrestrial system. In the same way, elements previously accumulated in marine ecosystems may become a part of limnic systems as these are formed. The approach used in this report is to describe a number of different aspects of pools and fluxes of elements in the landscape of today, and also take into consideration historical land use and ecosystem succession that are regarded as important for modelling radionuclide transfer and accumulation in an evolving surface system.

The initial chapters (3 and 4) in this report present an overview and synthesis of the site data presented in other reports (Appendix 3). In Chapter 4, the terrestrial landscape is described in terms of wetland, agriculture land and forest land. These vegetation types are described in terms of different aspects, such as species composition, present land use and ecosystem properties. Chapter 5 provides a conceptual description that serves as a basis for existing and future models. It consists primarily of descriptions of pools and fluxes of organic matter, but

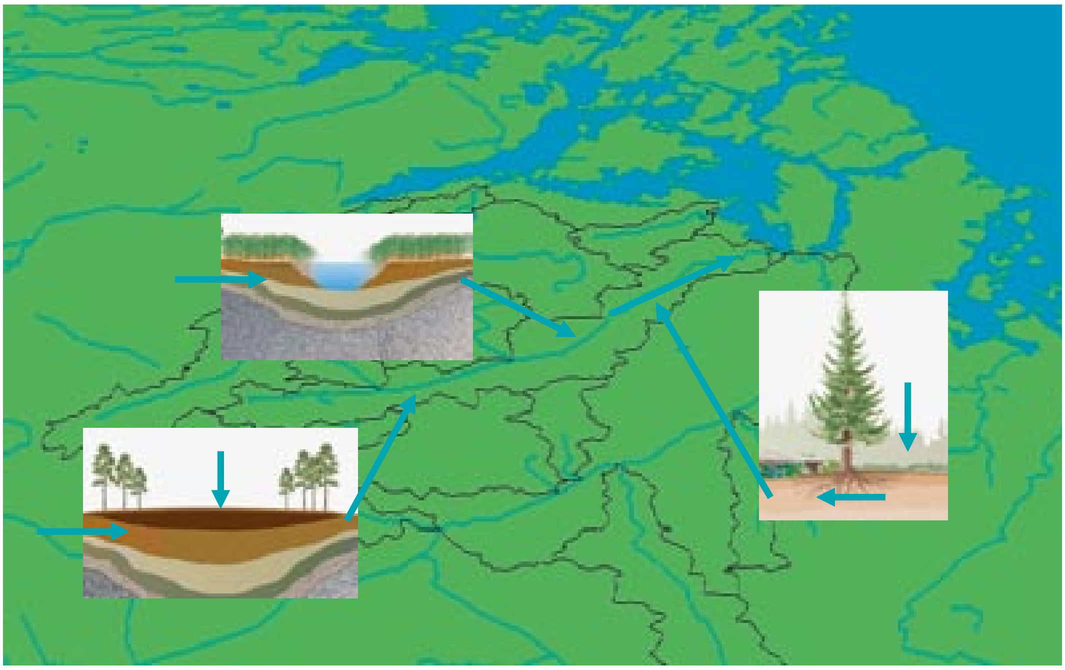

Figure 2-2. *A general description of water transport on the landscape scale, where a cross-disciplinary approach, integrating ecology, hydrology, Quaternary geology and chemistry, is used to describe element transport and accumulation in different ecosystems.*

also serves as a conceptual approach for describing pools and fluxes of other elements present in the ecosystems. Chapter 6 offers detailed descriptions of pools and fluxes of carbon, a proxy for organic matter, for three localities at each site where data have been collected. Chapter 7 takes a novel approach where the model LPJ-GUESS is used to estimate pools and fluxes of carbon for different vegetations types at both sites using climate as the driving variable. The results obtained from this model are combined with remote sensing data in order to study the variation in Net Primary Production (NPP) of the tree layer. In addition, long-term dynamics of a number of ecosystem properties are studied for forest and agricultural land at both sites. Chapter 8 uses information from Chapters 4 and 7 in combination with the vegetation map to describe the pools and fluxes of organic matter on the catchment scale with a more approximate conceptual model based on the conceptual description in Chapter 5. In Chapter 9 pools and fluxes are used to explore mass balances of phosphorus, iodine, uranium and thorium together with a large number of different elements on the catchment and landscape scales. Chapter 10 describes the postglacial terrestrial development, vegetation change and successional trajectories at the sites. In addition, the historic human land use is also an important component that has in many ways shaped the landscape of the past and present. Chapter 11 is a concluding chapter about how the ecosystems at the sites could be characterized and treated, and how this knowledge should be used in the coming safety assessment.

2.3 Delimitation of a terrestrial ecosystem

In the site descriptions the landscape is divided into three ecosystems: limnic, marine and terrestrial. The general difference between 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 plant life form, plant water availability and decomposition (see also Section 4.1.1). The interface between terrestrial and aquatic systems often shows high primary production and accumulation of organic material, e.g. a reed belt in a lake. Some interface areas are highly productive, but lack accumulation, e.g. exposed sea shores with input of marine residues. In some cases, the interface is easy to distinguish, e.g. an outcrop-water interface, but in other cases the boundary between land and water may not be so clear and easy to identify. In general, the interface on a freshwater shore is clearly distinguished, covering a transect of a few metres (the littoral of a lake), whereas a sea shore, with larger fluctuations in water level, may cover a transect of tens of metres. Zones of high production and accumulation, such as reed belts, have been identified around lakes and in sheltered bays in both the Forsmark and Laxemar-Simpevarp areas. In the ecosystem models, these zones are classified as wetlands and treated as part of the terrestrial ecosystem so that all kinds of wetlands are treated in a similar way. The interface zones are regarded as a transient stage in the succession of sea basins/lakes to land.

2.4 Geographical definitions and terminology

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

2.5 Conceptual, descriptive and numerical models

A number of different terms are used in this report, and some of the most frequently used of these are presented in Table 2-1. The terms are also described in the text.

Table 2-1. Definitions of terms used in this report.

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. Synonymous Here 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 an ecosystem. May be static or dynamic (see below).
Dynamic model	A dynamic model describes the behaviour of a spatially distributed parameter system in terms of how one qualitative state can turn into another.
Ecosystem model	Conceptual or mathematical representation of an ecosystem. Breaks complex food webs down into their major components or trophic levels and quantifies them as either numbers of organisms, biomass or the inventory/concentration of some pertinent chemical element.
Flux	Flow of energy or material from one pool to another.
Food web	Group of organisms that are linked together by a transfer of energy and nutrients that originates from the same source.
Functional group	Collection of organisms based on morphological, physiological, behavioural, biochemical, environmental or trophic criteria.
Gross primary production (GPP)	Net carbon input to an ecosystem – that is, net photosynthesis expressed at an ecosystem scale (gC m^{-2} yr^{-1}) /Chapin et al. 2002/.
Heterotroph	Organism that consumes organic matter produced by other organisms rather than producing organic matter from CO_2 and environmental energy. Includes decomposers, consumers and parasites /Chapin et al. 2002/.
Mass balance	A model describing the import and export of elements or matter in a system, making it possible to identify unknown mass flows or estimate mass flows that are difficult to measure.
Net ecosystem production (NEP)	The difference between gross primary production and ecosystem respiration /Chapin et al. 2002/. $NEP=\Delta C_{org}+E+O_{Xnb}-I$, where ΔC_{org} is the change in organic C storage in the ecosystem, E is the export of organic C, O_{Xnb} is the non-biological oxidation of C and I is the import of organic C /Lovett et al. 2006/.
Net primary production (NPP)	The difference between gross primary production and plant respiration.
Pool	Quantity of energy or material in an ecosystem compartment such as plants or soil /Chapin et al. 2002/.
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, while ecosystem respiration is heterotrophic plus autotrophic respiration /Chapin et al. 2002/.

3 General description of the sites

The two sites are briefly outlined with regard to climate, Quaternary deposits and vegetation before a more detailed presentation of the sites is presented in the next chapter.

3.1 The Forsmark area

3.1.1 Abiotic settings

Quaternary deposits

All known Quaternary deposits in the Forsmark area were formed during or after the last glaciations (Figure 3-1). The oldest deposits are of glacial origin, deposited directly by the ice, or by water from the melting ice. The whole area is located far below (> 120 m) the highest coastline, so the area has been located under the sea during the major part of the Holocene. Fine-grained sediment has been deposited in local depressions such as the bottom of the lakes and on the present-day sea floor. Wave action and currents have partly eroded the upper surface of the overburden. Isostatic uplift at Forsmark is still ongoing (6 mm/year), resulting in new land areas emerging from the Baltic. The most notable change in the areas uplifted from the Baltic is the development of organic soils, for example the sedimentation of gyttja in the lakes and the formation of peat in the wetlands. Peat formation is, however, more evident upon leaving the immediate coast and moving inland, where time has allowed a larger peat layer to accumulate. The minerogenic Quaternary deposits are affected by coastal and soil-forming processes at the surface, but no major redistribution of these deposits has occurred since the area was uplifted. The Forsmark area has less clay and silt (8% compared with 20%) and more till (65% compared with 41%) compared with the national averages. For a complete summary of current knowledge of the Quaternary deposits in the Forsmark area, see /Hedenström and Sohlenius 2008/.

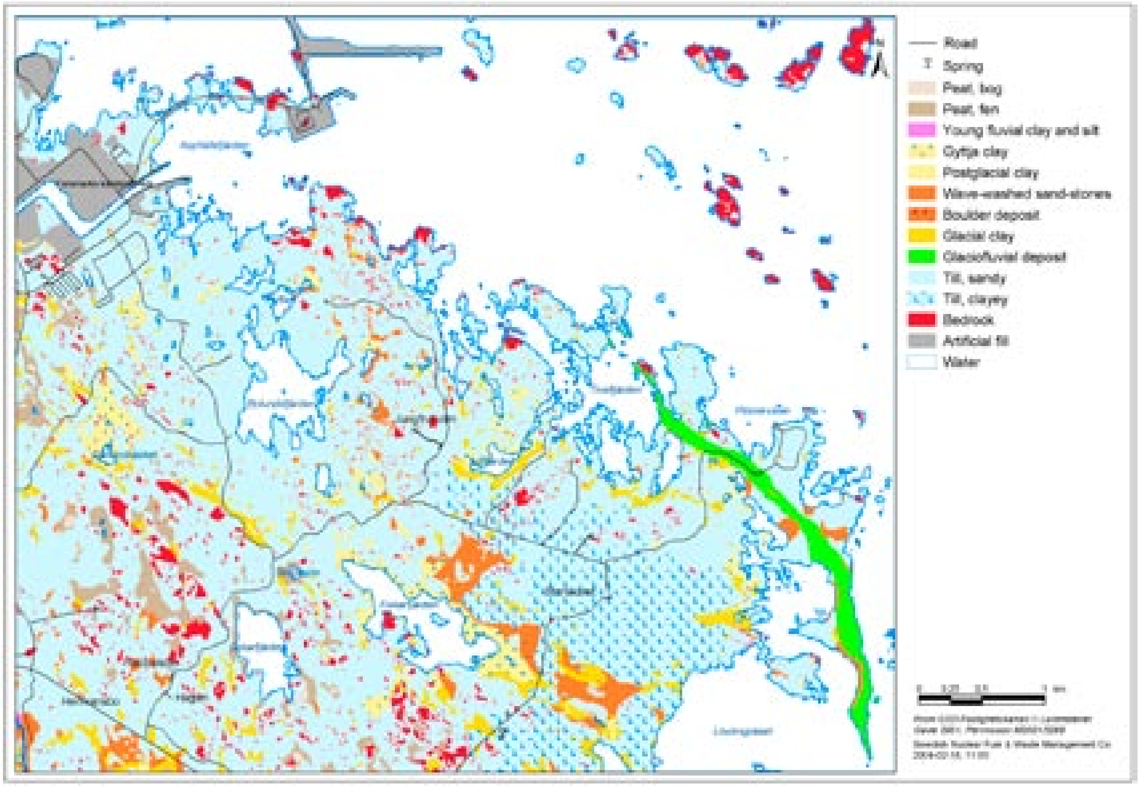

Figure 3-1. *The spatial distribution of Quaternary deposits in Forsmark /Hedenström and Sohlenius, 2008/.*

The surface water and shallow groundwater in Forsmark is characterized by high pH values and high contents of major constituents, especially calcium and bicarbonate /Sonesten 2005, Tröjbom and Söderbäck 2006a/. The main reason for this is the glacial remnants, mostly in the form of a till layer, which were deposited during the Weichselian glaciation and deglaciation /Fredén 2002/. This till layer has high calcite contents originating from the sedimentary bedrock of Gävlebukten about 100 km north of Forsmark. The calcareous influence is typical for the north-eastern part of Uppland County and is manifested in the flora. This is especially evident closer to the coast of the Baltic, due to the more recently uplifted areas that have been less exposed to weathering.

Soil types

The soils in the Forsmark area are typically immature, unweathered, poorly developed soil types on till or sedimentary parent material, which is influenced by calcareous material /Lundin et al. 2004/. The dominant soil types are Regosols but six other soil types also occur. Soils influenced by water, e.g. Gleysols and Histosols, are also frequent (Table 3-1). The spatial distribution of these soil types is described in Figure 3-2. Typical soils for Sweden are Podsols, but this soil type has not yet developed in the Forsmark area. The poor soil development is a result of young age, since most of the candidate area emerged from the sea during the last 1,500 years. As the sea withdrew it altered the soil by wave action at exposed sites, which has partly washed out the surface layer of the till and redistributed the fine-grained material into thin sedimentary deposits. In exposed positions the regolith was partly washed away, and at many sites there is bare rock or very thin soil cover. Furthermore, former bays of the Baltic which were uplifted and isolated now form inland lakes and ponds which are being transformed into swamps and peatland. This has resulted in a heterogeneous area with a large variety of soil parent material, from bare bedrock to wave-washed till and water-laid sediments.

Climate and hydrology

The corrected mean annual precipitation was 537 mm for three years of measurements at Högmasten and Storskäret (Jan. 2004–Dec. 2006). The mean annual potential evapotranspiration during the same period is estimated to 509 mm. The annual temperature during the same period was close to +7°C (Table 3-2). The 30-year long term annual average precipitation for 1961–1990, calculated by SMHI, was 559 mm.

Snow cover has been measured weekly during five seasons (2002/03–2006/07) at two sites in forest land and one site in open land. During four of these seasons the water content of the snow cover has also been determined. During the period of measurement there was a snow cover 105 and 80 days/season on average on forest land and open land, respectively. In general there was a snow cover from the end of November/beginning of December until the end of March/beginning of April. However, during some of the seasons there were periods when the snow cover

Table 3-1. Distribution of soil types for the central part of the Forsmark area updated after /Lundin et al. 2004/, see /Hedenström and Sohlenius 2008/.

Code	Soil class	Forsmark area (%)
	Unclassified	5.1
HI	Histosol	11.2
GL	Gleysol	2.3
GL/CM	Gleysol/Cambisol	24.4
RG/GL	Regosol/Gleysol	42.2
RG/GL-a	Regosol/Gleysol on arable land	6.8
AR/GL	Arenosol/Gleysol	1.8
RG	Regosol	1.5
LP	Leptosol	4.7

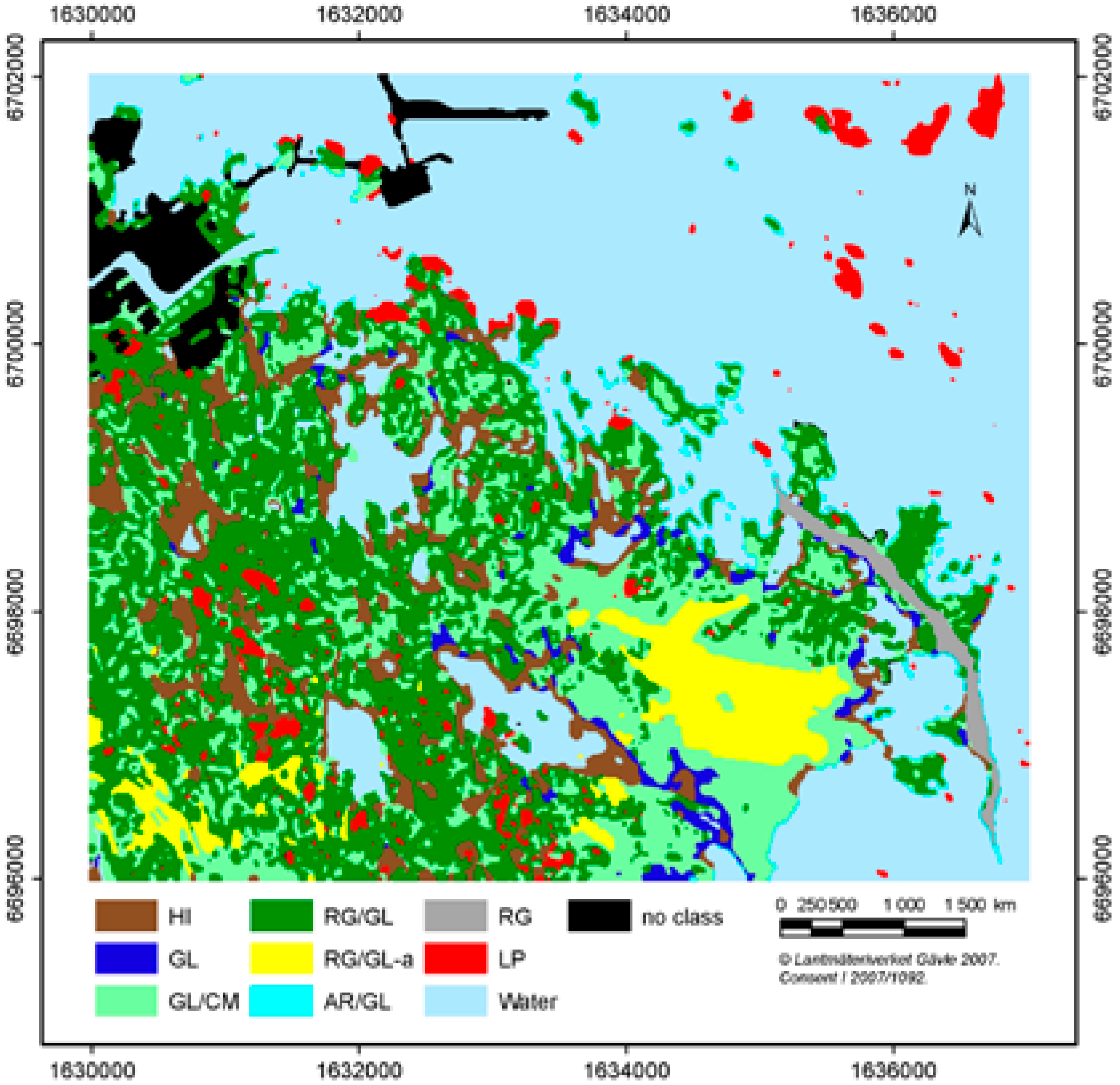

Figure 3‑2. *The spatial distribution of different soil types in Forsmark /Hedenström and Sohlenius 2008/. Soil type codes correspond to soil classes in Table 3‑1.*

Table 3‑2. Some climate characteristics for the Forsmark area. Data are for 2004 to 2006 for Storskäret, Forsmark /Johansson 2008/.

	Forsmark area
Latitude, longitude	60° 22’ N, 18° 11’ E
Mean annual temp. 2004–2006	+7°C
Min.–max. daily temp. 2004–2006	–14 – +25°C
Mean precipitation (mm)	546
Growing season	May–September
Growing season* 2004–2006	204 days

*Starts when 5 consecutive days have a daily mean >+5°.
Ends when 4 consecutive days have a daily mean <+5°.

disappeared. The maximum snow depth recorded was 48 cm in forest land and 25 cm in open land, and the maximum snow water content was 144 and 64 mm, respectively. For details on the measurements, see /Aquilonius and Karlsson 2003, Heneryd 2004, 2005, 2006, 2007/.

Based on measurements of precipitation, surface discharge, surface water levels and groundwater levels during the period April 15, 2004–April 14, 2007, and taking into account deviations from long-term average precipitation and storage changes, the long-term overall water balance in the area has been roughly estimated: Precipitation = 560 mm/year, actual evapotranspiration = 400–410 mm/year, and runoff=150–160 mm/year.

Ground frost penetration was measured during three seasons, 2003/04–2005/06, at two sites on forest land and at one site on open land. Ground frost was present for 40 and 80 days/season in forest land and open land, respectively. The maximum ground frost depth on open land was 46 cm, while the maximum depth on forest land was only 8 cm. For details on the measurements, see /Aquilonius and Karlsson 2003, Heneryd 2004, 2005, 2006 and 2007a/.

In total, 25 "lake-centred" catchments, ranging in size from 0.03 to 8.7 km^2, have been delineated and described within the model area. The 25 mapped lakes range in size from 0.006 km^2 to 0.75 km^2. The lakes are very shallow, with maximum depths ranging from 0.4 m to 2.0 m. No major water courses flow through the central part of the candidate area and few brooks downstream carry water most of the year, but can still be dry for long periods during dry years such as 2003 and 2006. Many brooks in the area have been artificially deepened for considerable distances for drainage purposes. Wetlands are frequent and cover 10–20% of the areas of the three major catchments, and up to 25–35% of some sub-catchments. Groundwater levels in Q deposits are very shallow, on average less than 0.7 m below ground for 50% of the time. Shallow groundwater levels imply a strong interaction between evapotranspiration, soil moisture and groundwater. Diurnal fluctuations of the groundwater levels, driven by evapotranspiration cycles, are evident in many groundwater wells. Furthermore, groundwater level measurements in the vicinity of the lakes show that the lakes may act as recharge sources to till aquifers in the riparian zone during summer. No major water courses flow through the central part of the candidate area and a few brooks downstream carry water for most of the year, but may still be dry for long time periods during dry years such as 2003 and 2006. Many brooks in the area have been artificially deepened for considerable distances for draining purposes.

3.1.2 Vegetation

The terrestrial vegetation is strongly influenced by the characteristics of the Quaternary deposits and by human land use. The area is fairly young (see 3.1.1 "Soil types") and have a low topography /Strömgren and Brydsten 2008/. The seaside location makes the seashore a prominent feature in the east. Most of the Forsmark land area is covered with conifer forests, where Scots pine (*Pinus sylvestris*) and Norway spruce (*Picea abies*) dominate (Figure 3-3, 3-4, Table 3-3). The low topography makes shallow lakes and mires common in the area. Most of the lakes are surrounded by mire vegetation with different extents depending on the depth of the lake and how far the succession of the lake has proceeded. Agriculture land is scarce in the area, but the main area is located in the southeast part of the investigation area. The spatial distribution of a number of different vegetation types was presented by /Boresjö Bronge and Wester 2003/ in a vegetation map that was based on remote sensing (SPOT4, 1999), soil map and field checks, see Figure 3-4 and Table 3-3. This map was updated with regard to clear-cuts in the area using information from the Swedish Forest Agency for the period mid-2000 to mid-2006. The vegetation map was verified by checking the consistency of the map against reality for a number of vegetation types by field visits /Alling et al. 2004a/. They concluded that the map identified wetlands with acceptable accuracy, but was less accurate in predicting fertile tree-dominated land from less fertile coniferous woodland.

Figure 3-3. *A view of the Forsmark area.*

Table 3-3. Vegetation classes and their spatial coverage in percent of the covered land area (water excluded).

Gridcode	Vegetation type	Area (m^2)	Coverage (%)
11	Old spruce-dominated forest, mesic-wet types	8,126,818	10
12	Young spruce-dominated forest, mesic-wet types	4,221,306	5
13	Old pine-dominated forest, mesic-wet types	8,719,747	11
14	Young pine-dominated forest, mesic-wet types	6,486,363	8
15	Dry pine forest on acid rocks	2,541,419	3
21	Birch-dominated forest	1,871,781	2
23	Aspen-dominated forest	23,690	0.03
26	Ash-dominated forest	1,540,700	2
30	Mixed forest (conifers/deciduous)	4,865,145	6
31	Mixed forest/shrub on bedrock islands	88,237	0.1
41	Old clear-cut, young spruce	398,160	0.5
42	Old clear-cut, young pine	781,956	1
43	Old clear-cut, unspecified conifer	7,088,887	9
44	Old clear-cut, birch thicket	9,516,768	12
45	Old clear-cut, birch thicket/meadow type	1,144,614	1
46	Poor regrowth, meagre ground, boulders	1,878,380	2
50	New clear-cut (2000–2006)	1,025,800	1
61	Forested wetland, spruce-dominated	157,839	0.2
62	Forested wetland, pine-dominated	896,073	1
63	Forested wetland, birch-dominated	1,374,568	2
64	Forested wetland, clear-cut	80,956	0.1
72	Open wetland, lush carpet mire/mud-bottom mire	64,113	0.1
74	Open wetland, lush lawn mire	417,976	1
75	Open wetland, lush lawn mire, with willow, birch	1,347,612	2
76	Open wetland, lush lawn mire, with willow, birch	801,049	1
77	Open wetland, reed-dominated, less wet	3,373,328	4
78	Open wetland, reed-dominated/more lush	551,085	1
79	Open wetland, reed-dominated, wet	413,921	1
81	Arable land	4,068,104	5
82	Other open land (pastures and meadows)	4,337,595	5
83	Coastal rocks	1,189,429	1
91	Holiday house	775,459	1
92	Industry	767,631	1
93	Lowrise house	142,154	0.2
96	Other hard surfaces (e.g. asphalt)	1,297,861	2

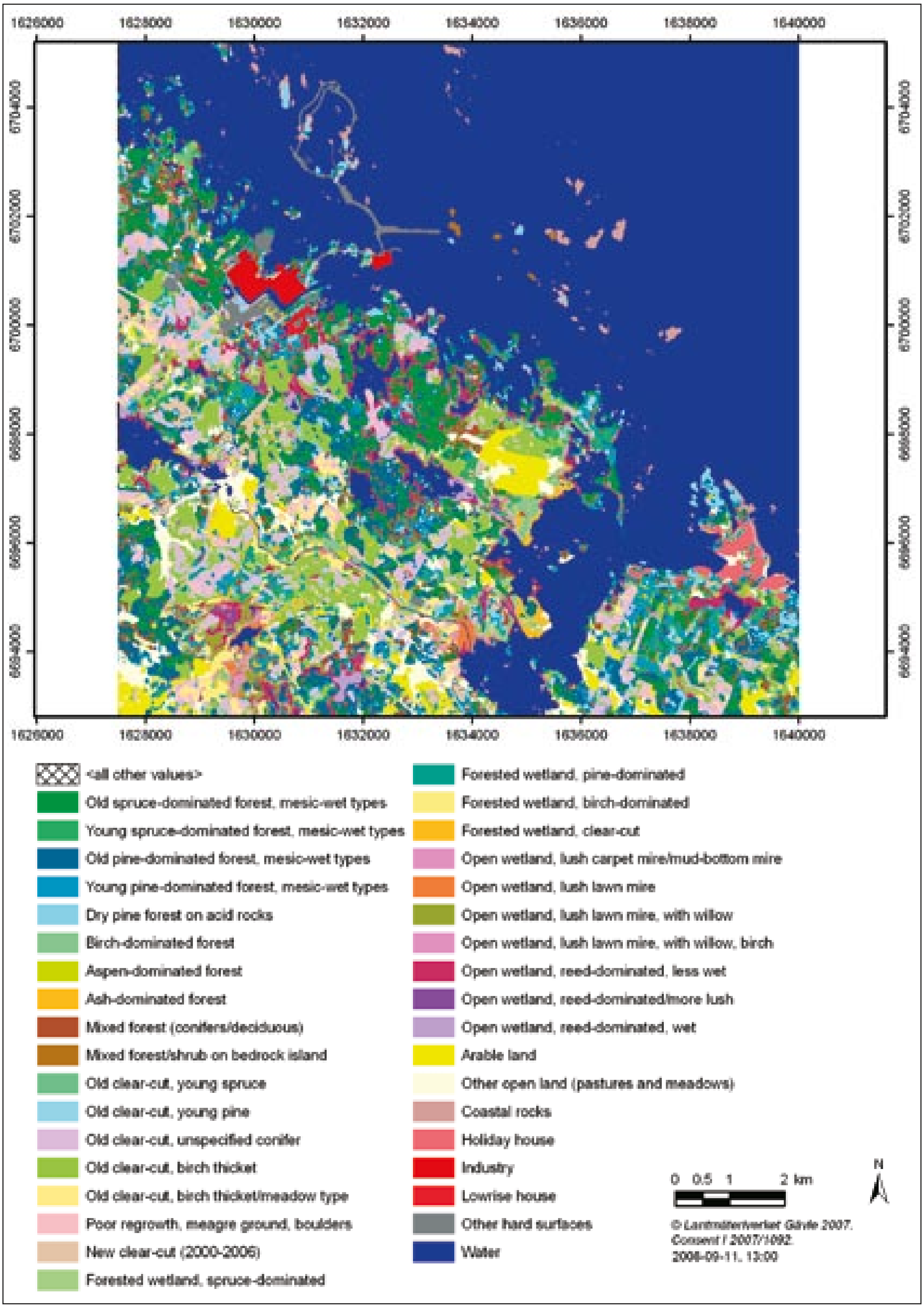

***Figure 3-4.** Vegetation map of the Forsmark area, which is a partially updated version based on /Boresjö Bronge and Wester 2003/.*

3.2 The Laxemar-Simpevarp area

3.2.1 Abiotic settings

Quaternary deposits

In a regional perspective the Laxemar-Simpevarp area is situated in a region with a relatively thin cover of Quaternary deposits. Both the marine and terrestrial parts of the investigated area are characterized by a relatively flat bedrock surface with numerous fissure valleys, which in many cases can be followed for several kilometres. The highest topographical areas are dominated by till and bedrock outcrops (Figure 3-5). The valleys in the Laxemar-Simpevarp area have been sheltered from wave erosion and coastal currents. These low topographical areas have therefore been favourable environments for sedimentation of clay during long time periods. In the terrestrial part of the model area, the groundwater level in the valleys is situated close to the ground surface. As a consequence, a layer of peat often covers the clay. Clay sediments are currently being deposited in the bays along the present coast. Exposed areas have been, and at some sites still are, subjected to wave washing, which has caused erosion and redeposition of some of the regolith. Sand and gravel is currently being transported at the bottom of the most exposed parts of the sea. A sand and gravel layer therefore often covers the valleys at the sea bottom. Forest covers the areas dominated by till and exposed bedrock, which constitute the main part of the investigated area. The areas covered with clay and peat in the valleys are, however, often used as arable land. Artificial ditches have lowered the groundwater table in these cultivated areas.

Soil types

The dominant soil is Podzol/Regosol, comprising thin coniferous forest soils found on till and course sediment soil with fresh soil moisture class (Figure 3-6, Table 3-4). Leptosol covers a mosaic of bedrock outcrops and thin soils typically found in upslope locations in the area. Similar to this class is bedrock, which is distinguished from the latter by the absence of a tree layer, but may have sparse pines, and a field layer of the dry heath type. Umbrisol-Regosol has a fresh soil moisture class and is dominated by deciduous trees in the tree layer, although some mixed forests occur. The Umbrisol-Gleysol type includes open pastures, partly forested moist soils in downslope locations and non-arable soil on clay and silt deposits. A number of histosols were identified and differentiated depending on their surrounding context, i.e. wetland on peat lacking a tree layer, forested peatland in forest-covered drained peatland soils, small peatland in bedrock areas.

Climate and hydrology

The regional mean annual precipitation in the Laxemar-Simpevarp area has been estimated to be 600 mm (Table 3-5) /Werner 2008/. The mean annual temperature in the Laxemar-Simpevarp region is 6–7°C. The mean temperature in January is –2°C and mean temperature in July is 16–17°C. Thereby, the temperature in Laxemar-Simpevarp is about 1°C warmer (in January 2°C) than in the Östhammar/Tierp region.

Approximately 17% of the accumulated precipitation during the period Sep. 9, 2003–Dec. 31 fell in the form of snow /Werner 2008; see above/. Snow cover has been measured approximately biweekly during the period 2002/03 to 2006/07 at station ASM100224, Grillplatsen, Äspö. Generally, there was a snow cover from December/January until March/April during this period. However, short periods of snow were recorded as early as October, and late snow cover was recorded at the end of April. The period of snow cover at Grillplatsen, Äspö agrees well with the measured snow cover at four SMHI stations. Snow cover has been measured at the SMHI stations since 1994, making it possible to estimate snow cover for longer time periods in the Laxemar-Simpevarp area. Some kilometres inland from Oskarshamn the ground is covered by snow for on average about 75 days a year, with an average yearly maximum snow depth of 35–40 cm. The coast does not differ much from the conditions 10–20 km inland /Larsson-McCann et al. 2002a/.

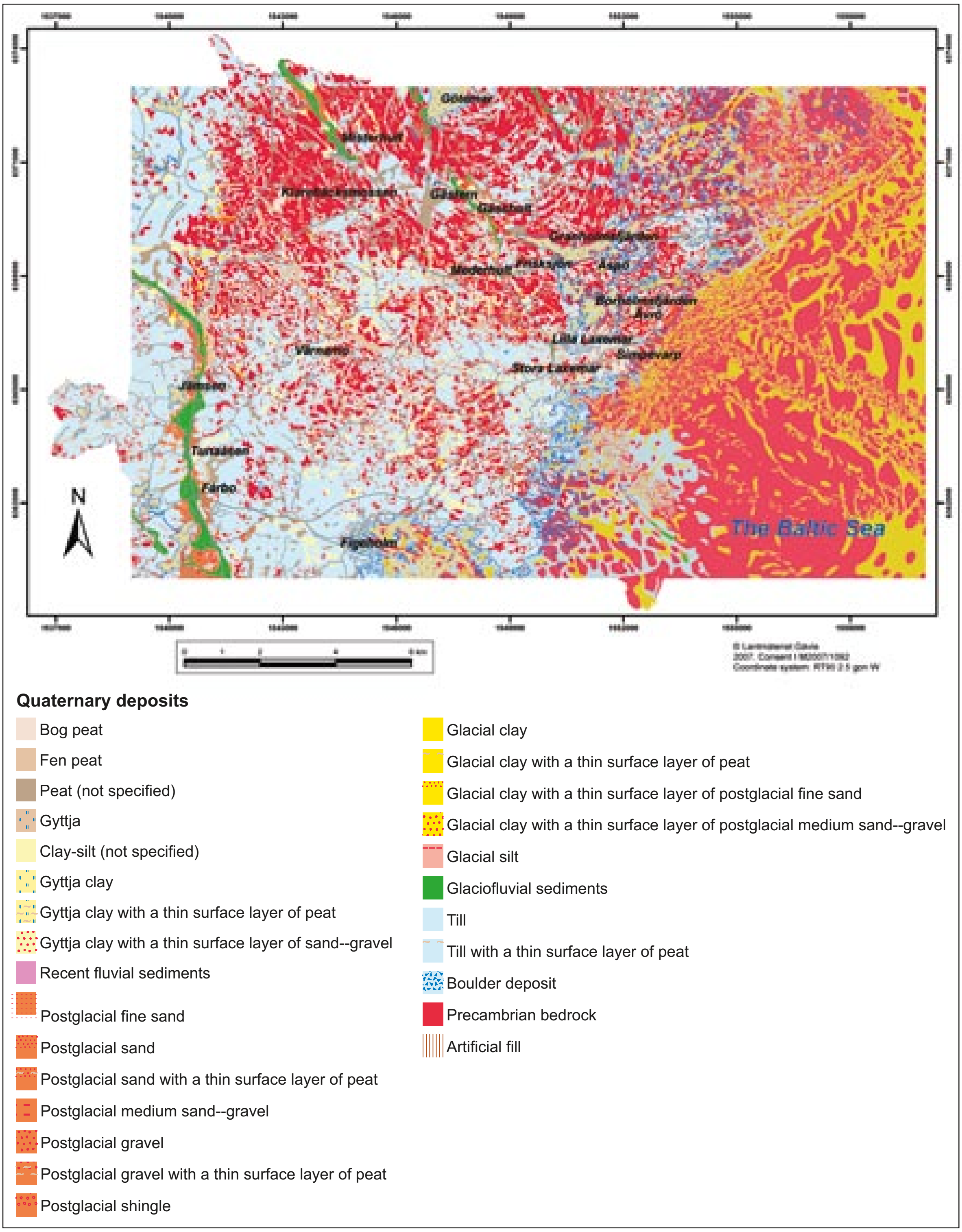

Figure 3-5. *Spatial distribution of Quaternary deposits in the Laxemar-Simpevarp regional model area. Areas covered by water are shaded with grey /Sohlenius and Hedenström 2008/.*

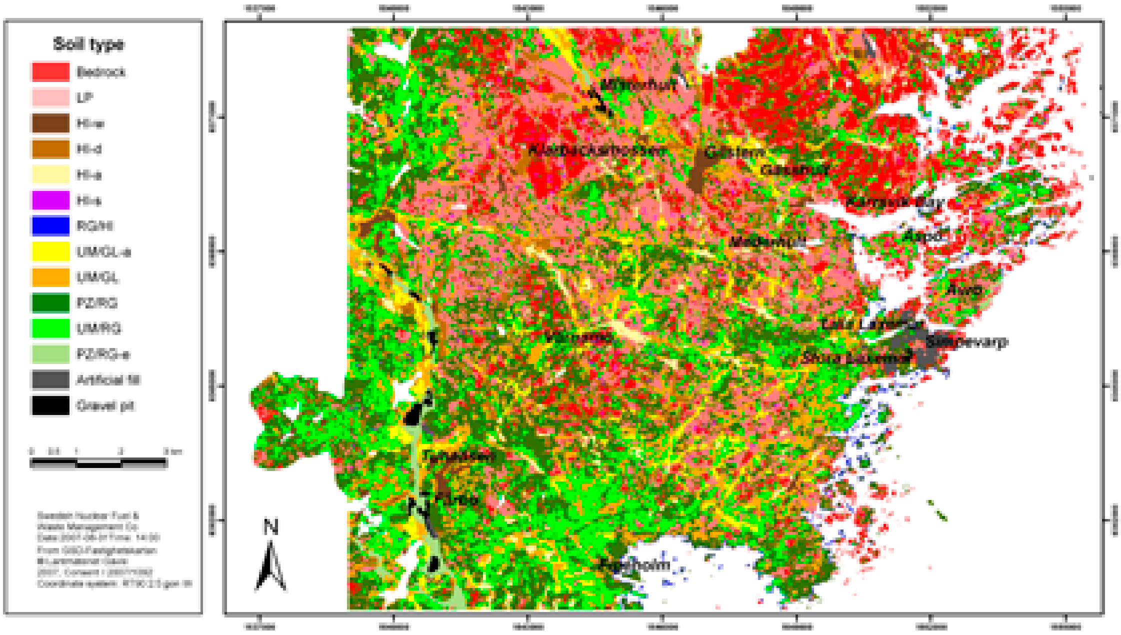

Figure 3-6. Spatial distribution of different soil types in Laxemar-Simpevarp area. The map is based on field studies and interpretations of other geographical information such as maps of QD and vegetation. Since the most detailed mapping of QD took place in the Laxemar River catchment, the soil map is more reliable in that area /Sohlenius and Hedenström 2008/. Soil type codes correspond to soil classes in Table 3-4.

Table 3-4. Spatial coverage of the soil classes in the Simpevarp regional model area. From /Sohlenius and Hedenström 2008/.

Soil class	Land type	GIS map soil class	Laxemar-Simpevarp regional model area Coverage (%)
No soil	Exposed bedrock	Bedrock	11.1
Leptosol	Mostly rock outcrops and till with coniferous forest	LP	23.6
Podzol/Regosol	Mostly till in areas with coniferous forest	PZ/RG	25.2
Podzol/Regosol	Glaciofluvial material with coniferous forest	PZ/RG-e	1.4
Umbrisol/Regosol	Deciduous forest in till-dominated areas	UM/RG	15.7
Umbrisol/Gleysol	Meadows	UM/GL	10.9
Histosol	Forested peatlands, artificially drained	HI-f	3.7
Histosol	Open wetlands	HI-w	1.7
Histosol	Arable land, artificially drained	HI-a	1.7
Histosol	Small peatlands	HI-s	0.6
Regosol/Histosol	Shoreline areas, dominated by till	RG/HI	0.6
Umbrisol /Gleysol	Arable land, mostly artificially drained	UM/GL-a	2.8
No soil	Artificial fill	Artificial fill	0.6
No soil	Gravel pit	Gravel pit	0.4

Table 3-5. Some climate characteristics for the Laxemar-Simpevarp area. Data are for 2004–2007 for Äspö, Simpevarp /Werner 2008, Werner et al. 2008/.

	Simpevarp
Latitude, longitude	57º 25’ N, 16º 33’ E
Mean annual temp.	+8°C
Min.–max. daily temp.	–14 – +24°C
Mean annual precipitation (mm)	600
Growing season	April–October
Growing season* 2004–2007 (Äspö temp. data)	224 days

*Starts when 5 consecutive days have a daily mean >+5º.
Ends when 4 consecutive days have a daily mean <+5º.

Precipitation demonstrates a near-coastal gradient, with less precipitation at the coast compared to areas further inland. Based on long-term meteorological data from surrounding stations, the Swedish Meteorological and Hydrological Institute (SMHI) has estimated the 30-year (1961–1990) annual average precipitation to be 553 mm for the Äspö station (on the coast) and 630 mm for the Plittorp station (further inland). For the three years 2005–2007, for which data are available from all discharge-gauging stations (monitoring commenced at one station in Feb. 2005), the site-average specific discharge can be estimated to be c 165 mm y^{-1} (or c 5.2 L s^{-1} km^{-2}), which is within the interval of the regional long-term average estimated by /Larsson-McCann et al. 2002a/. During the same period (2005–2007), annual average precipitation was c 580 mm on Äspö and c 620 mm in Plittorp, whereas potential evapotranspiration was c 540 and 530 mm y^{-1}, respectively. Based on available site investigation data, the site-average water balance for the years 2005–2007 can thereby be estimated to be P = 600 mm y^{-1}, ET (actual evapotranspiration) = 435 mm y^{-1} and R (specific discharge) = 165 mm y^{-1}.

Measurements of ground frost penetration at four locations in the Laxemar-Simpevarp area show that the ground is generally frozen from approximately the middle of November until the middle or end of March. The measured frost depth is usually in the interval 0.05–0.15 m. Depending on air temperature and snow depth, the frost depth can be up to 0.5 m (Äspö, Grillplatsen, Feb. 2003), but winter observations also show zero frost depth (e.g. Grindstugan, Jan. 2006).

The main lakes at the site are Jämsen (0.24 km^2), Frisksjön (0.13 km^2), Sörå (0.10 km^2), Plittorpsgöl (0.03 km^2), Fjällgöl (0.03 km^2) and Grangöl (no size data). These relatively small lakes are shallow, with average depths in the range 1–4 m and maximum depths in the range 2–11 m. All lakes are located above sea level, which means that no sea water intrusion takes place. Wetlands cover a total of c 3% of the delineated catchment areas /Brunberg et al. 2004b/.

Most streams in the Laxemar-Simpevarp area are affected by land improvement and drainage operations. The flow in the streams demonstrates seasonal variability; in particular, the smaller streams are dry during a large part of the year. Groundwater levels in Quaternary deposits are shallow, on average less than 1 m below the ground surface during c 50% of the time. Groundwater-level monitoring below lakes indicates that there is generally little interaction between lake water and groundwater in Quaternary deposits, and it is limited to near-shore areas.

3.2.2 Vegetation

The area is young for the same reasons as in the Forsmark area, see 3.1.1 “Soil types”, but has a higher-relief topography than the Forsmark area e.g. /Brydsten and Strömgren 2005/. A number of intersecting valleys are surrounded by higher-lying till and bedrock outcrops, and agricultural land is located along the valleys. Most of the Laxemar-Simpevarp area is covered with conifer forests, where Scots pine and Norway spruce dominate (Figure 3-7, 3-8, Table 3-6). Mires are common but not to the same extent as in the Forsmark area. Many of the lakes are surrounded by some mire vegetation, whose extent depends on the depth of the lake and how far the succession of the lake has proceeded. The spatial distribution of a number of different vegetation types was reported by /Boresjö Bronge and Wester 2003/ in a vegetation map that was constructed in the same way as for the Forsmark area and later updated with regard to clear-cuts using information from the Swedish Forest Agency for the period mid-2000 to mid-2006 (Figure 3-8, Table 3-6).

Figure 3-7. *A view of the Laxemar-Simpevarp area.*

Table 3-6. Vegetation classes and their spatial coverage in percent of the covered land area (water excluded).

Gridcode	Vegetation type	Area (m²)	Coverage (%)
11	Old spruce-dominated forest, mesic-wet types	5,476,403	2
12	Young spruce-dominated forest, mesic-wet types	5,351,123	2
13	Old pine-dominated forest, mesic-wet types	52,072,419	21
14	Young pine-dominated forest, mesic-wet types	4,548,817	2
15	Dry pine forest on acid rocks	30,424,644	12
23	Coastal deciduous forest (birch/oak) or thicket on clear-cuts on coastal rocks	3,273,737	1
24	Birch forest or oak/maple mixed with conifers (pine/spruce)	6,498,417	3
25	Oak-dominated deciduous forest	3,847,137	2
30	Mixed forest (conifers/deciduous)	34,778,576	14
41	Old clear-cut, young spruce	1,058,477	0.4
42	Old clear-cut, young pine	23,521,837	9
43	Old clear-cut, unspecified conifer	21,795,895	9
44	Old clear-cut, birch thicket	17,003,778	7
45	Old clear-cut, birch thicket/meadow type	1,887,515	1
50	New clear-cut 1999–2006	7,909,199	3
62	Forested wetland, pine-dominated	1,956,094	1
63	Forested wetland, birch-dominated	1,229,725	0.5
71	Open wetland, hummock mire	323,297	0.1
72	Open wetland, poor lawn mire	727,681	0.3
73	Open wetland, lush lawn mire	299,972	0.1
74	Open wetland, very lush lawn mire, with tall herbs	402,731	0.2
75	Open wetland, very lush lawn mire, with willow	91,407	0.04
76	Open wetland, poor carpet mire, *Sphagnum*-dominated	33,936	0.01
77	Open wetland, lush swamp fen	543,738	0.2
78	Open wetland, lush swamp fen, reed-dominated	1,522,632	1
79	Open wetland, reed-dominated, poorer or wetter	960,251	0.4
80	Floating mats/macrophytes	134,344	0.1
81	Arable land	9,075,976	4
82	Other open land (pastures and meadows)	9,428,792	4
83	Coastal rocks	1,424,564	1
85	Sand or stone pit	576,021	0.2
91	Holiday house	142,066	0.1
92	Industry	111,277	0.04
93	Lowrise house	884,420	0.4
96	Other hard surfaces (e.g. asphalt)	1,219,829	0.5

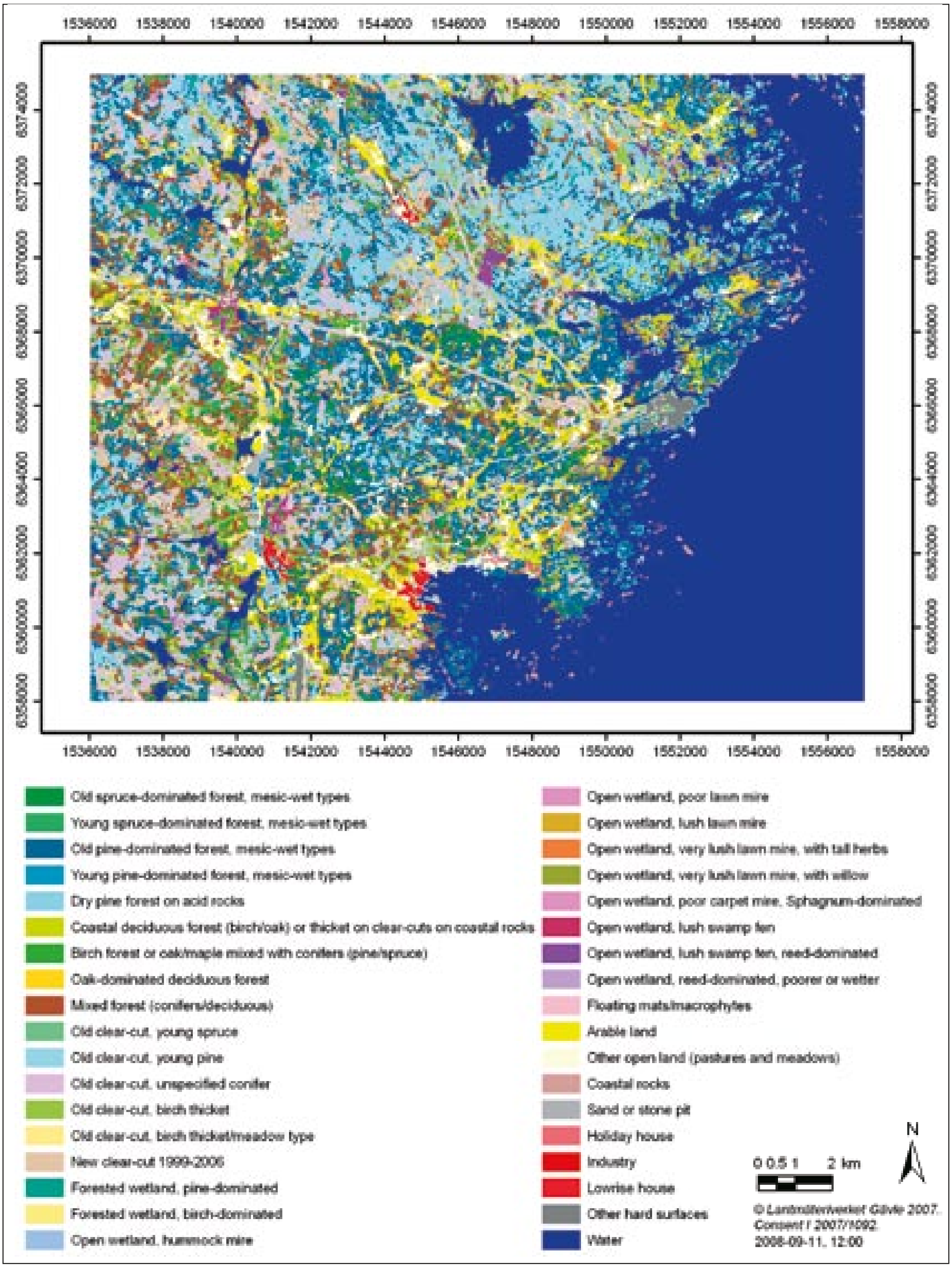

__Figure 3-8.__ Vegetation map of the Laxemar-Simpevarp area, which is a partially updated version based on /Boresjö Bronge and Wester 2003/.

4 Detailed descriptions of the terrestrial areas and their characteristics at the two sites

This chapter describes terrestrial biotic and abiotic properties that define and characterize the terrestrial areas in Forsmark and Laxemar-Simpevarp. These descriptions cover important components of the terrestrial ecosystem, such as Quaternary deposits, vegetation, fauna, and interactions between different parts of the ecosystem. They will also be used and further elaborated on in the following chapters.

The landscape was divided into three main ecosystems: lake, sea and terrestrial. The aquatic systems are further described by /Nordén et al. 2008 and Wijnbladh et al. 2008/. Wetland ecosystems are regarded as being part of the terrestrial systems (as opposed to aquatic systems) due to similar soil and plant processes (see Section 4.1.1 for a more detailed description).

4.1 Vegetation

The vegetation in the terrestrial system is classified into three major vegetation types: wetlands, agricultural land and forests. This subdivision was chosen due to differences in ecosystem processes, land use and the feasibility of detecting these ecosystems in reality, e.g. by remote sensing. This classification of the vegetation should not be confused with a static view of the landscape, but is rather a convenient way of describing the landscape at a certain point in time.

4.1.1 Wetlands

Introduction

Wetland ecosystems have unique characteristics because they are transition areas and ecological interfaces between aquatic and terrestrial ecosystems in a landscape. Two unique characteristics of wetlands are the waterlogged soil and the resulting anaerobic conditions /Mitsch and Gosselink 2000/. They possess properties from both aquatic and terrestrial systems and provide many ecological services as sources, sinks and transformers of a large number of chemical and biological materials, for example peat accumulation. Due to their hydrological properties also provide unique habitats in the landscape that serve as nurseries and feeding areas for a large variety of both terrestrial and aquatic species. Wetlands have been called “biological supermarkets” because of the extensive food web and rich biodiversity that they maintain /Mitsch and Gosselink 2000/.

There is a large diversity of wetlands and some of them are among the most productive ecosystems on earth. In general, many names exist for wetland ecosystems and as many as 27 common terms for various wetland types in the world were found by /Mitsch and Gosselink 2000/ The mires in the Nordic countries can be divided into five main groups that can be subdivided into vegetation types and sub-groups /Nordiska Ministerrådet 1998/. Because wetlands are a diverse group of ecosystems, it is often a challenge to define and classify them. In this report, we use the following overall definition of wetlands:

Wetlands are land where water, during a large part of the year or all year round, is close to, under, at or just above the ground surface /from Landin 2002/. In addition, wetlands must have one or more of the following three attributes: (1) at least periodically, the land supports predominantly hydrophytes (plants that are adapted to wet habitats); (2) the substrate is predominantly undrained hydric soil; and (3) the substrate is non-soil and is saturated with water or covered by shallow water at some time during the growing season of each year /from Cowardin et al. 1979/.

Water zones covered with floating vegetation or with submersed species and sparse reed growth, and water zones with a water depth up to 2 m, often included in wetlands, are considered to be a part of the lake or sea ecosystems in this site description. The reason for excluding these water zones from the wetland ecosystem is that the material produced in the littoral zone does not accumulate to the same extent in those areas; instead it is washed out and accumulates at the bottom of the lake or sea.

Location and function

Climate and geomorphology are the major parameters that define the degree to which wetlands can exist. Hydrology affects the physicochemical environment, including the soils, and together they determine what and how much biota, including vegetation, is found in the wetland /Mitsch and Gosselink 2000/.

Wetlands are often situated downstream in watersheds and in depressions that receive large surface runoff or where infiltrated precipitation comes to the surface. Wetlands also alter the hydrology of streams and rivers by impeding water flow and enhancing sediment deposition, and thereby function as a filter for coastal waters with the ability to retain nutrients as well as contaminants. Wetlands have therefore been called “the kidneys of the landscape” /Mitsch and Gosselink 2000/.

Wetlands can be divided into the following functional groups: permanent wetlands, which are constantly saturated, and temporary wetlands, with periodic inundation and a dry period. Permanent wetlands are in general less productive than temporary or seasonal wetlands and some are very unproductive /Horne and Goldman 1994/. The small amount of available oxygen slows down sediment decomposition and nutrient recycling and peat deposits accumulate if conditions are acidic. Permanent wetlands in temperate and tropical climates are generally dense stands of a few species of grasses, reeds or specially adapted trees. In cool, wet, alpine or polar climates, vascular plants are generally scant and the wetland is composed of infertile and acidic peat bogs of *Sphagnum* and other moss species. Temporary wetlands typically have a periodic inundation and a dry period when the whole or most of the wetland regains terrestrial conditions. During the dry season, the decomposed plants produce a rich particulate organic base for the next season’s detritivores. The decomposition process releases some inorganic as well as organic nutrients to the soils. These can in some cases be flushed out during the early spring flooding or be incorporated in organisms that consume water from the wetland. This cycle of wet and dry periods can make these wetlands very productive during the wet period. High rates of primary production usually occur in spring, when wetlands are particularly important as nursing grounds for e.g. birds, fish, amphibians and insects.

Colloidal and particulate material has a high capacity for adsorbing many radionuclides, and the large amount of water seeping through the wetlands may result in an accumulation of radionuclides in these ecosystems. The numbers and position of wetlands in the landscape may hence have a major impact on the transportation of radionuclides. Accordingly, some types of wetlands (temporary inundated floodplains, riparian swamps) are known to accumulate nutrients and contaminants such as radionuclides /Mitsch et al. 1979, Stark et al. 2006/. However, no major water flows are currently to be found on either of the two sites /Nordén et al. 2008/.

In addition to soil properties, topography and vegetation are also of great importance for retention of particulates and associated radionuclides in a wetland ecosystem /Mungur et al. 1995/. For example, when a river or a stream is in flood, the running water, containing colloids and particles, inundates the wetland. Here the water velocity is impeded and the colloids and particles will start to sediment on the ground surface. If the wetland area contains large amounts of tall vegetation, the vegetation itself may filter the colloids and particles in the water. The water velocity will also slow down faster if there is tall and thick vegetation on the inundated area, enhancing the sedimentation rate. The result will be that colloids and particles settle on the vegetation and on the ground surface in the wetland. Radionuclides with a high affinity for colloids and particles such as ^{137}Cs will be greatly affected by these processes (Table 4-1).

Table 4-1. Factors that influence retention of radionuclides (particles), especially ^{137}Cs, in wetlands, /after Stark et al. 2006/.

Factor	Condition	Mechanism of retention	Reference
Type of soil	peat or mineral soil	^{137}Cs high affinity for clay minerals	/Sawhney 1972, Broberg and Andersson 1991, Avery 1996/
Duration of saturation	permanent or temporary	dry periods; in constantly saturated area ^{137}Cs is more mobile	/Nylén and Grip 1991, Hilton et al. 1993, Saxén 1994/
Type of vegetation	tall or short, thick or scarce	tall and thick vegetation filter colloids and particles	/Horrill 1984, Mungur et al. 1995/
Degree of salinity	marine water or freshwater	freshwater; in saline water Cs^+ is more mobile	/Horrill 1984/
Level of pH	high, neutral, low	high or neutral pH: high level of H^+-ions (low pH) releases Cs^+ from soil particles	/Munthe et al. 2001/
Level of nutrients in soil	high or low	high uptake of ^{137}Cs by plants if low K^+ and high NH_4^+ concentration	/Camps et al. 2003/
Topography	elevated or low areas	hollows and depressions can enhance sediment deposition	/Jeffries et al. 2002, Van Der Perk et al. 2002/

Wetland nomenclature

In English-speaking countries, wetlands are divided on the basis of structure into the following groups: bog and fen, marsh, and swamp. In this site description, the following wetland groups are used, based on the Swedish system for enhancing biological diversity /Landin 2002/: mires (bogs and fens), freshwater shores (wet meadows, marshes, reed belts (*Phragmites*) along lakes and running water), marine shores, and forested wetlands (deciduous and coniferous forest swamps; Table 4-2). Forested wetlands are treated as a separate group (even though some could be classified as e.g. mires) because they often show great biodiversity and are therefore important in risk assessment.

Table 4-2. Wetland groups with subclasses used in this report. After /Landin, 2002/ and /TemaNord 1994:665/.

1. Mires
  - a) bogs
  - b) fens
    - poor fens
    - intermediate fens
    - rich fens
    - extremely rich fens

2. Freshwater shores
  - a) wet meadows
  - b) marshes
  - c) reed belts

3. Marine shores

4. Forested wetlands
  - a) deciduous forest swamps
  - b) coniferous forest swamps

Bogs are peat-accumulating wetlands that have no significant inflows or outflows and support acidophilic mosses, particularly *Sphagnum* species. Fens are also peat-accumulating wetlands, but they receive some drainage from the surrounding mineral soil and usually support marsh-like vegetation. This results in a more alkaline pH than found in bogs, which never reach a higher pH than the pH of the precipitation. Freshwater shores along streams and lakes are defined as regularly or constantly inundated wetlands characterized by emergent herbaceous vegetation adapted to saturated soil conditions. In European terminology, wet meadows and marshes do not accumulate peat and have a mineral soil substrate /Mitsch and Gosselink 2000/. Reed belts can accumulate reed peat along lake shores and along sheltered brackish water sea shores which are part of the marine shores. Forested wetlands (swamps) are wetlands dominated by trees or shrubs. In Europe, wetlands dominated by reed are sometimes included in the sub-class swamps, but not in this report (Table 4-2).

Wetlands in the Forsmark area

In the Forsmark area, wetlands occur frequently and cover 10–20% of the area in the three major catchments and up to 25–35% in some sub-catchments /Johansson et al. 2005/ (Figure 4-1). The spatial coverage of different wetland types, forested and open wetlands, in relation to the total land area was estimated based on a vegetation map /Boresjö Bronge and Wester 2002/ (Table 4-3).

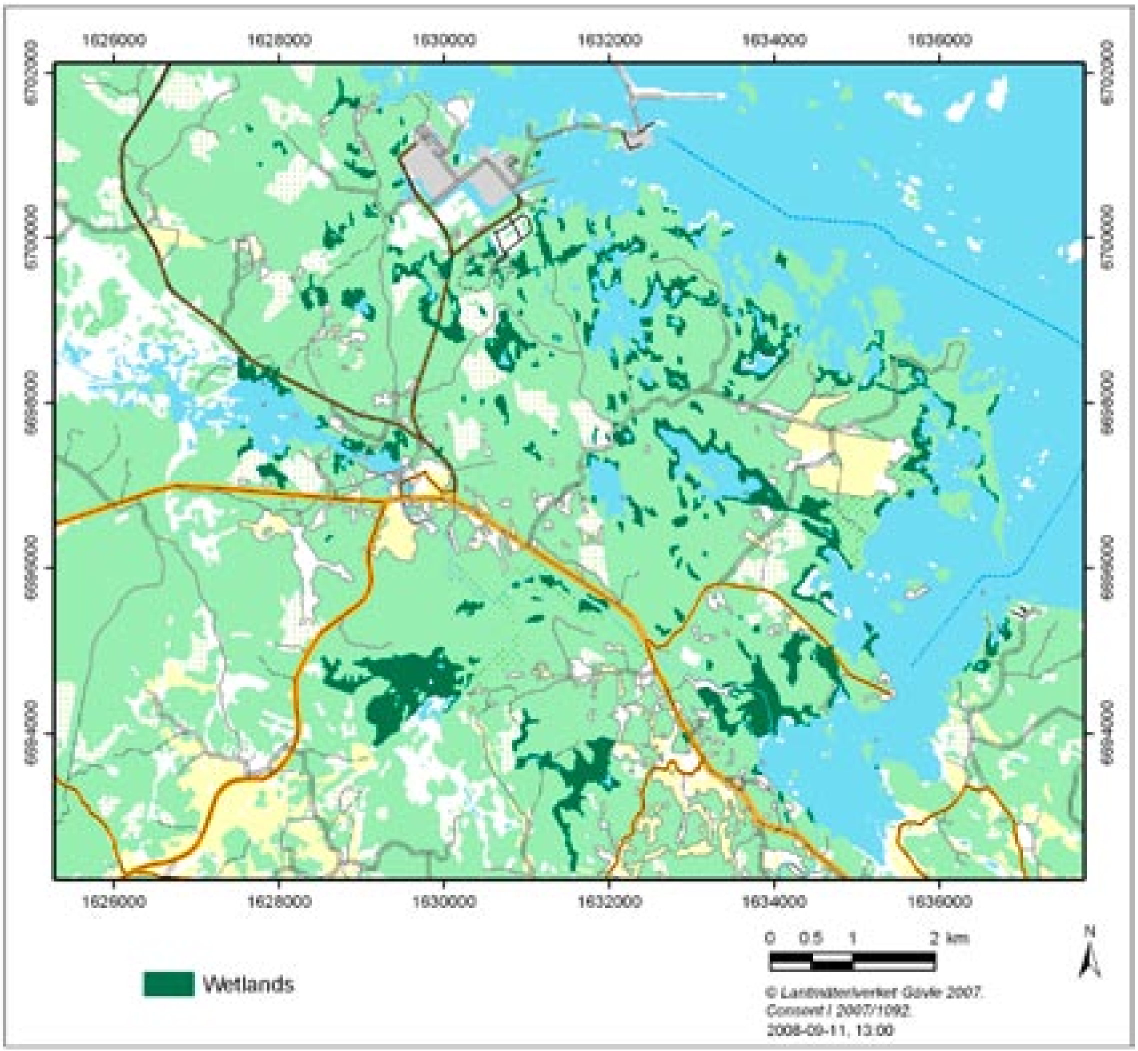

Figure 4-1. Wetlands identified in the Forsmark area.

Table 4-3. Wetlands in the Forsmark area. The number of objects, their total area, and their relative coverage of the total wetland area and total land area identified on the vegetation map /Boresjö Bronge and Wester 2003/.

Vegetation class	N	Area (ha)	% of wetland area	% of total area
Forested wetland	472	251	26.5	3.1
Open wetland	1,139	697	73.5	8.5

A major part of the wetlands in the Forsmark area are coniferous forest swamps and fens. The wetlands are characterized by a high calcareous influence, resulting in the extremely rich to intermediate fen types common in this area /Göthberg and Wahlman 2006, Jonsell and Jonsell 1995/. These fen types lack the dominance of *Sphagnum* species in the bottom layer and are instead dominated by brown mosses e.g. *Scorpidium scorpioides*. All mires were classified as calcareous (rich or extremely rich) fens except for one, and two were classified as mixed mires (with bog and fen characteristics) /Göthberg and Wahlman 2006/.

Most fens in the Forsmark area show indications of terrestrialization, resulting in new hydrological conditions when a fen replaces a lake. One cause of this is that many wetlands are heavily dominated by a dense and high stand of common reed (*Phragmites australis*) (Figure 4-2). Most fens investigated have at least some clear open water and sometimes a dense vegetation of *Charophytes* /Göthberg and Wahlman 2006/. In the Forsmark area, large bogs are rare because they have had too little time to develop in the young terrestrial environment (See wetland development in Chapter 10).

Figure 4-2. *A wetland in the Forsmark area dominated by reed (Phragmites australis).*

Other important wetland types found in the Forsmark area are the freshwater shores (wet meadows or marshes) and riparian deciduous forest swamps along streams that are inundated at least once a year by the stream and affected by overbank sedimentation (Figure 4-3). Such areas can function as sediment traps and thus as traps for nutrients and contaminants. An investigation conducted in parts of the Forsmark area indicates that the flat topography in the area promotes the occurrence of small floodplains in the area /Carlsson et al. 2005/. In their investigations, wetlands along three running waters in Forsmark reflect the general characteristics of the area: a flat lowland area close to the sea with small catchments. Accordingly, they suggest that surrounding wetland areas that are flooded during high-flow periods may be of importance for the retention of different substances that are transported by the water to the sea. The size of flooded areas adjacent to streams is further described in /Nordén et al. 2008/.

Wetlands in the Laxemar-Simpevarp area

Wetlands are less frequent here, covering only 3% of the area in the main catchments (Figure 4-4), and are characterized by nutrient-poor fens /Rühling 1997, SNV 1984/. Bogs are not yet so numerous in the area, partly due to the young age of the terrestrial environments and the low annual precipitation in the area /Rühling 1997/. Most of the wetlands in the Laxemar-Simpevarp area have one of two histories: former lakes or isolated sea bays that have become overgrown due to changed hydrological conditions, and wetlands adjacent to running waters subject to inundation /Rühling 1997/. In the region, wetland areas have been reduced to a great extent due to agricultural activities and extensive ditching. The riparian deciduous forest swamps and inundated wet meadows in particular have probably been reduced/ditched and used for agriculture. However, despite agricultural activities, these kinds of wetlands can still be found in the area. Some alder forest swamps are of small size (500 m^2) and have not been included on the vegetation map. Some peatland areas, former mires, are also used for forestry today.

The spatial coverage of different vegetation types, forested and open wetlands, in relation to the total land area was estimated based on a vegetation map /Boresjö Bronge and Wester 2003/ (Table 4-4).

Figure 4-3. *The largest running water in the Forsmark regional area, the Forsmark river. The bare soil at the river sides indicates fluctuating water levels. The river bank on the right is built up from fine sediments and organic material deposited by the river.*

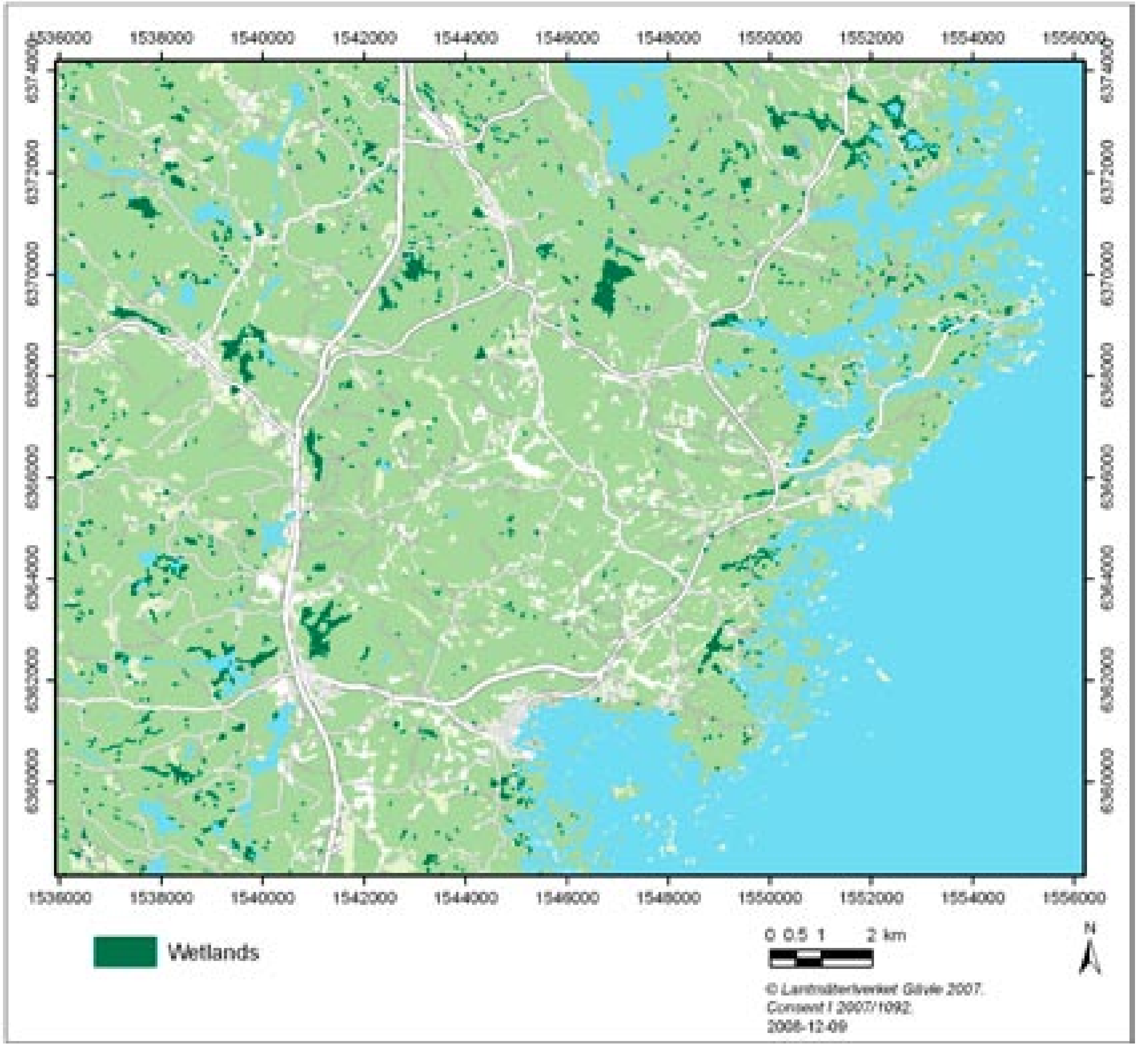

Figure 4-4. *Wetlands identified in the Laxemar-Simpevarp area.*

Table 4-4. Wetlands in the Laxemar-Simpevarp area. The number of objects, their total area, and their relative coverage of the total wetland area and total land area identified on the vegetation map /Boresjö Bronge and Wester 2003/.

Vegetation class	N	Area (ha)	% of wetland area	% of total area
Forested wetland	585	3,218	40	1.3
Open wetland	1,084	4,907	60	1.9

Flooded areas (riparian wetlands) along streams in catchments 6, 7, 9, and 10 (Figure 8-3) were investigated by /Strömgren et al. 2006/. The length of the stream stretch that was flooded during the period of investigation was noted. Most of the streams investigated (including Mederhultsån, Kåreviksån, Ekerumsån, and Simpevarpån) included flooded areas, although the stretches were often short in comparison to the total length of the stream (See also Table 4-1 in /Nordén et al. 2008/). Streams were also affected by human activities in several places and ran through underground pipes sometimes for long stretches /Strömgren et al. 2006/. The flooded areas of the streams most often occurred downstream close to the outlet into the sea (Figure 4-5). In the northern part of the area where bedrock is common, small peat-accumulating nutrient-poor wetlands are found in the depressions in the bedrock (Figure 4-6).

Figure 4-5. The largest river in the Simpevarp regional model area, the Laxemarån. The river bank is a regularly flooded deciduous forest on fine sediments deposited by the river close to the outlet into the sea.

Figure 4-6. A typical poor wetland in the northern part of the Laxemar-Simpevarp regional model area situated high, surrounded by bare rocks and Scots pine forest on shallow soil.

Wetland vegetation

The Forsmark area

The large amount of calcareous material in the till in the Forsmark area influences the vegetation and favours calciphilous plants. For example, brown mosses, especially *Scorpidium scorpioides*, are found in many fens where *Sphagnum* species usually occur /Lundin et al. 2004, Löfgren 2005/. Also, a number of orchids such as *Dactylorhiza incarnata*, *D. traunsteineri* and *Epipactis palustris* regularly occur in mires and coniferous forest swamps /Göthberg and Wahlman 2006, Jonsell and Jonsell 1995/ together with other calcareous influence indicator species such as *Carex appropinquata* and *Parnassia palustris* /Göthberg and Wahlman 2006/. Furthermore, more investigated mires had indicator species of calcareous influence than indicator species of bog-like conditions (total sum 114 and 88). In addition, a number of red-listed species have been found in the fens, e.g. *Carex pulicaris* /Göthberg and Wahlman 2006/ and *Liparis loesli* (Löfgren pers. obs.). *Phragmites australis* was dominant in larger fens /Lundin et al. 2004, Löfgren 2005/.

In addition, the results from /Göthberg and Wahlman 2006/ show that the vegetation pattern depends on the level above the sea (Figure 4-7). With increasing level above the sea, bog indicator species became more abundant (Regression, $p < 0.001$). This correlation would probably also be found for age of the wetland and number of bog species because the older wetlands are situated higher above the sea.

Small pools can be found along the rocky sea shores in the Forsmark area. The pools situated closest to the sea regularly receive an influx of brackish water from the sea and do not contain many plant species. In pools further up on the shores, species such as *Eleocharis mamillata*, *Carex acuta,* and *Sparganium angustifolia* occur /Jonsell and Jonsell 1995/. When a pool has ended up above the shoreline due to land uplift in the area, the pool changes its characteristics. The pool becomes nutrient poorer and *Polytrichum commune* and *Sphagnum* mosses start to appear. Eventually, miniature bogs are formed where *Rubus chamaemorus, Vaccinium uliginosum, V. oxycoccus,* and *Empetrum hermaphroditum* are established /Jonsell and Jonsell 1995/. Often the final stage bog is of such a small size that it is not indicated on the vegetation map by /Boresjö Bronge and Wester 2003/.

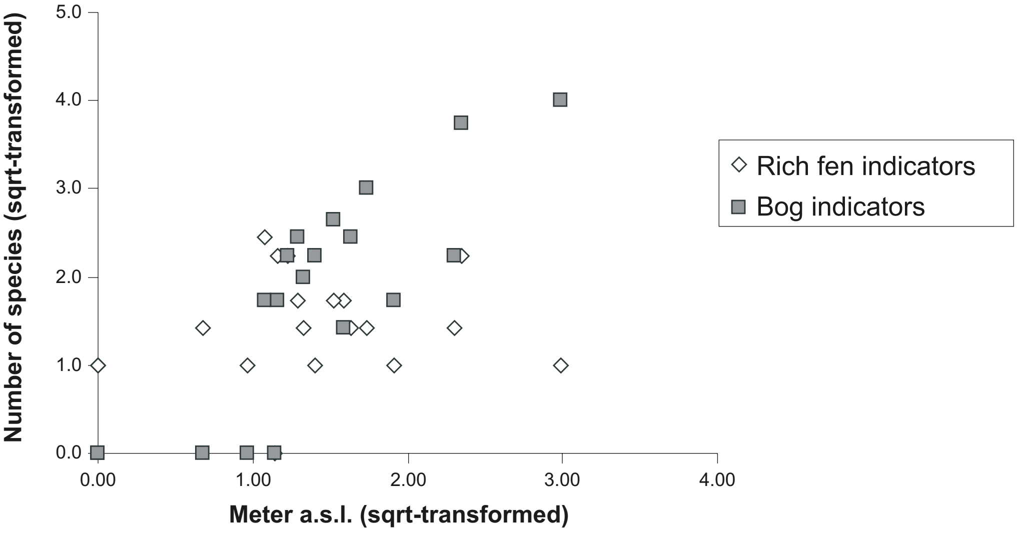

Figure 4-7. Number of species, bog indicators and rich fen indicators (calcareous influence), in relation to metres above sea level in the Forsmark area.

Shores with wave-washed till are most common in the Forsmark area, while rocky shores and shores with fine sediments also occur. The flat emerging till shores outside Forsmark have a sea shore vegetation zonation that is defined by their tolerance to water inundation and salt sprays /Jerling et al. 2001, Jerling 1999/. The first pioneer woody species is Hawthorn (*Hippophaë rhamnoides*), closely followed by the tree alder (*Alnus glutinosa*). Both these species have a litter that is rich in nitrogen, and this facilitates the establishment of many species. *Festuca rubra* is a common species on all types of marine shores in the area /Jonsell and Jonsell 1995/.

Wetlands along running waters belonging to the group freshwater shores were investigated by /Carlsson et al. 2005/. Vegetation growing along three streams that enter the Baltic Sea from the Forsmark area was identified (further described in /Nordén et al. 2008/. Tall herbs such as *Filipendula ulmaria, Lysimachia trifoliata, Iris pseudacorus* and the tree species *Alnus glutinosa* are often found in riparian alder forest swamps or floodplains functioning as sediment traps.

The Laxemar-Simpevarp area

Poor fens are the dominant type of mires in the Laxemar-Simpevarp area /Rühling 1997/. Vascular plant species found in these poor fens are *Menyanthes trifoliate, Galium palustre, Carex rostrata, C. lasiocarpa, C. panacea, C. echinata, Eriophorum angustifolium, Agrostis canina,* and *Molinia caerulea*. Intermediate fens that have a slightly higher nutrient content can also be found in areas with poor nutrient status if they have access to moving groundwater that increases the nutrient supply to the wetland. *Galium uliginosum, Succisa pratensis, Iris pseudacorus,* and *Carex elata* are often found in intermediate fens in the Laxemar-Simpevarp area. *Equisetum palustre* and *Parnassia palustris* are also occasionally observed. At the edge surrounding fens, usually a five to ten metre zone between the moss-covered part of the fen and surrounding land, tree species *Betula pubescens* and *Alnus glutinosa* and the bush species *Salix cinerea* and *Frangula alnus* are usually found.

As mentioned above, bogs are not so numerous in the Laxemar-Simpevarp area, whereas coniferous forest swamps (with *Pinus* sp.) are more common /Rühling 1997/. Common species in *Sphagnum*-dominated wetlands are *Drosera rotundifolia, Vaccinium oxycoccos, Andromeda polifolia, Rhododendron tomentosum, Rubus chamaemorus* and *Eriophorum vaginatum* /Rühling 1997/.

Marshes (*Sw. mader*) along streams and lakes occur mainly near the larger watercourses and are subject to flooding during periods of high flow. They are characterized by vascular plant species such as *Equisetum fluviatile, Stellaria palustris, Potentilla palustris, Peucedanum palustre, Lythrum salicaria, Lysimachia vulgaris, L. thyrsiflora, Alisma plantago-aquatica, Iris pseudacorus, Carex vesicaria, C. rostrata, C. acuta,* and *C. elata* /Rühling 1997/.

Common species in wet meadows with tall herbs are *Caltha palustris, Ranunculus acris, Thalictrum flavum, Filipendula ulmaria, Geum rivale, Geranium sylvaticum, Lythrum salicaria, Angelica sylvestris, Lysimachia vulgaris, Molinia caerulea* and *Deschampsia cespitosa* /Rühling,1997/. Wet meadows occur in areas with running groundwater, in discharge areas, and along creeks and streams.

The most common type of marine shore is the rock outcrop and boulder type, but marine meadows also occur in the area /Rühling 1997/. Marine meadows can be found adjacent to shallow bays where fine sediments deposit and these are dominated by *Festuca rubra, Agrostis stolonifera, Juncus gerardii, Blysmus rufus, Poa pratensis* ssp. *irrigata, Carex viridula* var. *pulchella, Eleocharis quinqueflora, Centaurium littorale, Ophioglossum vulgatum, Tetragonolobus maritimus, Trifolium fragiferum* and *Potentilla anserina*.

Alder forest swamp occurs in the Laxemar-Simpevarp area in moist stream valleys on nutrient-rich soils and near freshwater lake shores /Rühling, 1997/. Common species are *Athyrium filix-femina, Phegopteris connectilis, Stellaria alsine, Catha palustris, Ranunculus flammula, R. repens, R. auricomus, Cardamine pratensis* ssp. *dentata, Filipendula ulmaria, Geum rivale, Solanum dulcamara* and *Scirpus sylvaticus*.

Quarternary deposits

The Forsmark area

Current investigations in the Forsmark area indicate that most peatlands are shallow, having evolved from old lake sediments /Bergström 2001, Fredriksson 2004/. During the process of land uplift, the coastal waters of the Baltic Sea continuously became more and more shallow. Finally, the water became stagnant and shallow enough for sediment-rooted vegetation to become established, and a process of terrestrialization started to form the present peatland /Fredriksson 2004/. This can be recognized from the findings in most examined peat profiles. A thin layer of *Phragmites* peat is present at the bottom, above a layer of gyttja of varying thickness. Over the *Phragmites* layer, mostly fen *Carex* peat of a varying degree of humification or more humified fen wood peat is found. On one extensive peatland (an open bog), /Bergström 2001/ found *Sphagnum* peat directly above the *Phragmites* layer in what was previously open water. In the same peatland there were relatively thick layers of fen wood and *Phragmites* peat in areas that had presumably been more sheltered. The current lakes in the area are often bordered by zones of reed wetlands and wooded fens, while still open in the middle, which is consistent with terrestrialization. Depending on the size of the lake and its supply of water, the central parts of the lake subsequently fills up with bog or fen peat.

The most common final stage of the peatlands in this area is probably a pine bog. /Fredriksson 2004/ found that the wood-fen peat was usually highly humified, but the degrees of humification in the *Carex*-fen peat varied independently among the profiles within the same peatland, indicating a variation in conditions for decomposition. Peat has developed in the more elevated areas further up from the sea; the thickness of the peat is usually less than one metre. In more low-lying areas, the peat layer is very thin or missing. The peat is underlain by gyttja and sometimes also by sand and clay layers. From existing borings /Johansson 2003, Werner and Lundholm 2004/ it is known that the peat in the wetlands can rest directly on till or be underlain by gyttja and/or clay above the till.

The Laxemar-Simpevarp area

The peat areas include both current wetlands where peat is currently being formed and former wetlands where the groundwater table has been artificially lowered. Many of the current and former wetlands have, however, not experienced a lake stage and underwent primary mire formation directly after the area was lifted above sea level. Some of the wetlands situated close to the present sea level lack a peat layer, since too short a period has elapsed since the areas were lifted above sea level. The soils in most of the present and former wetlands are dominated by histosol. The peat in some of the former wetlands has disappeared because the lowered groundwater table causes the peat to compact and oxidize and the layer of peat is becoming progressively thinner /Sohlenius and Hedström 2008/, and umbrisol/gleysol has been formed. The areas covered by wetlands have decreased significantly in the landscape, due to the lowering of the groundwater table by ditches. That was done mainly for agricultural purposes but also to improve the rate of forest growth. Several of the areas used as arable land have names ending with “kärret” or “mossen” (fen or bog), indicating an origin as wetlands.

The somewhat larger wetlands not located on bedrock are predominately fens, where the vegetation gets water from the surrounding land areas. Some of the mires are bogs, however, where the vegetation only receives water from direct precipitation. The mires in the high topographical areas generally have a thinner cover of Quaternary deposits (QD) compared to the larger present and former wetlands situated in the bigger valleys. It might, however, be possible to find small pockets with a thicker layer of QD in these small wetlands.

The bottom stratigraphy of wetlands and peat areas in Laxemar-Simpevarp area was investigated by /Nilsson 2004/. The investigation included “true wetlands” (overgrown by reed, and with gyttja as the predominant type of QD), “true peat areas” (bogs and fens), and areas on “dry land”, with just a thin layer of peat or water-laid sediments overlying the till or bedrock /Nilsson 2004/. The investigation showed that a typical top-down stratigraphy in wetlands and peat areas is peat (when present), clay gyttja and gyttja, silt-sand-gravel, postglacial clay, and glacial clay. The individual layers are on the order of 0.5–2 metres, except for the silt-sand-gravel layers, which are generally very thin.

There are numerous small wetlands in the till- and bedrock-dominated areas in the northern part of the Laxemar-Simpevarp area. Most of these wetlands are covered by peat and are shown as histosol on the soil map /Lundin et al. 2005a/. It is possible that the area of peatlands in the Laxemar-Simpevarp area could be underestimated using maps, such as the soil map or the vegetation map, because of their small size.

Surface hydrology

The Forsmark area

The hydraulic contact between the wetlands and the surrounding shallow groundwater largely depends on the stratigraphy. Low-permeable sediments will restrict the discharge of groundwater from upgradient areas and result in a relocation of the discharge to areas where such sediments are missing. Wetlands are frequent in the more low-lying parts of the area. The gyttja in these wetlands can rest directly on till, or be underlain by clayey gyttja and/or sand and clay above the till. More fine-grained sediments indicate a less permeable layer, which means that the hydraulic contact with the surrounding groundwater system varies among wetlands in the area. Till is the dominant type of QD, covering approximately 75% of the area considered in the detailed mapping /Johansson 2008/.

No major watercourses flow through the area northeast of the main water divide to the Forsmarksån River. The annual variation in rainfall, snowmelt and evapotranspiration typically results in large flows in the brooks in the late autumn and in the spring following snowmelt. The streams downstream of the lakes Gunnarsboträsket, Eckarfjärden, and Gällsboträsket carry water most of the year, but may still be dry for long periods in dry years.

Possible future wetlands were studied in relation to hydrology and transport mechanisms by /Vikström and Gustafsson 2006/. Three lakes were chosen for the analysis: Bolundsfjärden, Eckarfjärden and Puttan. Because of its shallow depth, Bolundsfjärden will probably become a mire in the future. The lake is situated in the downstream part of the regional model area and receives runoff from upstream surface water systems. Eckarfjärden is situated in the upstream part of the catchment at a higher altitude and with a smaller inflow. Puttan is situated above a planned layout of the repository and has the potential to receive discharges from a repository. The lake also lies in the downstream part of a large discharge area. The analyses showed that the hydraulic conditions that exists today will be somewhat altered as peat is formed in the mires. In the case of Bolundsfjärden, a recharge area will be formed during the summer. The same will happen to Eckarfjärden, but Puttan will still be a discharge area after the peat has developed because of its naturally strong discharge position close to the sea.

Results from the transport modelling show that a solute in the bedrock is transported quickly towards the peat surface in discharge areas for Bolundsfjärden /Vikström and Gustafsson 2006/. After about 10 years, a steady state is reached. In the recharge area that develops in large parts of the mire, the solute is transported by horizontal dispersion, which results in much lower concentrations. Puttan has a vertical flow pattern that differs from Bolundsfjärden. The pressure of water on the peat surface is considerably lower, and for a major part of the year, Puttan is a discharge area with an upward flow direction.

The Laxemar-Simpevarp area

The main watercourses in the Laxemar-Simpevarp area have been described by /Brunberg et al. 2004b/ (Figure 8-3). They are further treated in /Nordén et al. 2008/.

There are wetlands in 20 of the 26 catchment areas identified in the Laxemar-Simpevarp area /Brunberg et al. 2004b/, and they only cover about 3% of the area. The results from the investigations of QD show that many of the wetlands in the Laxemar-Simpevarp area contain peat, and that the peat is often thinner than one metre /Rudmark 2004, Rudmark et al. 2005/. Many wetlands that contain peat have been drained. It is therefore likely that drying and oxidation have made the peat cover thinner. The groundwater table in relatively small wetlands has usually not been artificially lowered.

The bottom stratigraphy of wetlands and peat areas in the Laxemar-Simpevarp area was investigated by /Nilsson 2004/. The investigation included "true wetlands" (overgrown by reed, and with gyttja as the predominant type of QD), "true peat areas" (bogs and fens), and areas on "dry land", with just a thin layer of peat or water-laid sediments overlying the till or bedrock /Nilsson 2004/. The investigation showed that a typical top-down stratigraphy in wetlands and peat areas is peat (when present), clay gyttja and gyttja, silt-sand-gravel, postglacial clay, and glacial clay. The individual layers are on the order of 0.5–2 metres, except for the silt-sand-gravel layers, which are generally very thin. Hence, the results indicate that the bottom layers of the wetlands and peat areas consist of low-permeable materials, indicating limited interactions between groundwater and surface water in these areas.

Management today

In both the Forsmark and Laxemar-Simpevarp areas, as in the rest of Sweden, the agriculture and forestry industries are still affecting wetland hydrology to some extent by cutting trees and building roads for e.g. forest machines that may entail drainage and destruction of wetlands. Other activities in Sweden that entail drainage of wetlands today include peat cutting, construction of roads, development, and construction of golf courses.

Peat cutting for energy production was resumed in the 1980s, after some years of no production, as a result of the energy crisis in the 1970s with rising oil prices. The cutting of peat totally changes the land and the hydrology in the area that is exploited /Svanberg and Vilborg 2001/. When a mire (with a peat layer of at least 40 cm) is used for peat cutting, the field layer is taken away and the area is extensively drained. As a consequence, water-dependent plants and animals in the mire disappear. Adjacent lakes and water courses are also affected by the changes in ecology and hydrology on the mire. Peat cutting on mires usually occurs for 20 years. However, peat cutting for soil improvement purposes can go on for a longer period. When the cutting is ended, the mire is transformed into some type of wetland or is used for forestry. Peat cutting areas occur today near both the Forsmark area in Uppsala County and near the Laxemar-Simpevarp area in Kalmar County /SCB 2000/.

In addition, golf courses have been built in both Uppsala and Kalmar county /SCB 2000/, but it is unclear whether these projects have entailed any ditching of wetlands.

In the Laxemar-Simpevarp area, a considerable amount of the arable land that replaced former wetlands in the woodlands remains open to this day. This land is now used for the production of hay. Only a few of the arable areas from the period of expansion in the 19th century are currently abandoned and are now either wooded or covered with bushes and small trees. Some former wetlands revert into wet areas when the former ditches become overgrown, but most former wetlands become wooded areas.

Ecosystem properties

Wetland functions or processes can be placed in five ecosystem-level categories: hydrologic flux, productivity, decomposition, biogeochemical cycling, and community and wildlife habitat /Richardson 1994/. Productivity, decomposition and biogeochemical cycling will be discussed in this section. Carbon will play a major role in the discussion since it is the major constituent of peat.

Biomass and primary production

Supplies of water and nutrients are the major factors for carbon accumulation in the ecosystem, driven by the process of photosynthesis /Chapin et al. 2002/. Wetland productivity is generally very high, and the rate of primary productivity can greatly exceed that of grasslands, cultivated lands, and most forests (Figure 4-8) /Richardson 1995/. The largest flux of carbon is the gross primary production (GPP) in the field and bottom layer, of which approximately 50% is the net primary production (NPP). A large part of the NPP is turned into litter from both above-ground and below-ground plant functional parts. The biggest pool of carbon can be found in the soil, mainly as peat /Chapin et al. 2002/.

/Brinson et al. 1981/ reviewed the primary productivity of freshwater wetlands, and the mean net biomass production of nonforested wetlands was found to vary between 400 and 900 gC m^{-2} y^{-1}. The above-ground biomass of Finnish mires was found to vary between 200 gdw m^{-2} in wet fens and 20,000 gdw m^{-2} in forested spruce swamps /Laine and Vasander 1996/, with the highest values including the tree biomass. The highest field layer biomass values are usually found in dwarf shrub rich site types, where *Ledum palustre* and *Betula nana* dominate /Laine and Vasander 1996/. In addition, a large field layer biomass is produced by communities dominated by tall sedge species. /Löfgren 2005/ investigated the biomass and NPP in the field and bottom layer of an open mire and a forested wetland in the Forsmark area and in the Laxemar-Simpevarp area. The results showed that the most productive field and ground layers overall were in the vegetation types that lacked a tree layer (Table 4-5).

Several investigations have been conducted in order to calculate the biomass of dense reed stands, in order to be able to characterize both mires, preferentially in the Forsmark area, wetlands next to lakes and shallow bays (Table 4-6). The relationship between above-ground (AG) biomass and below-ground (BG) biomass seems to be highly variable. /Löfgren 2005/ found the mean AG biomass to be 6% of the BG biomass for five samples in a sheltered sea bay in the Laxemar-Simpevarp area, whereas /Alling et al. 2004b/ found it to be 43% as a mean of six sea bays in the same area. These two studies did not differentiate between living and dead roots, which most certainly can be a large part of the BG biomass.

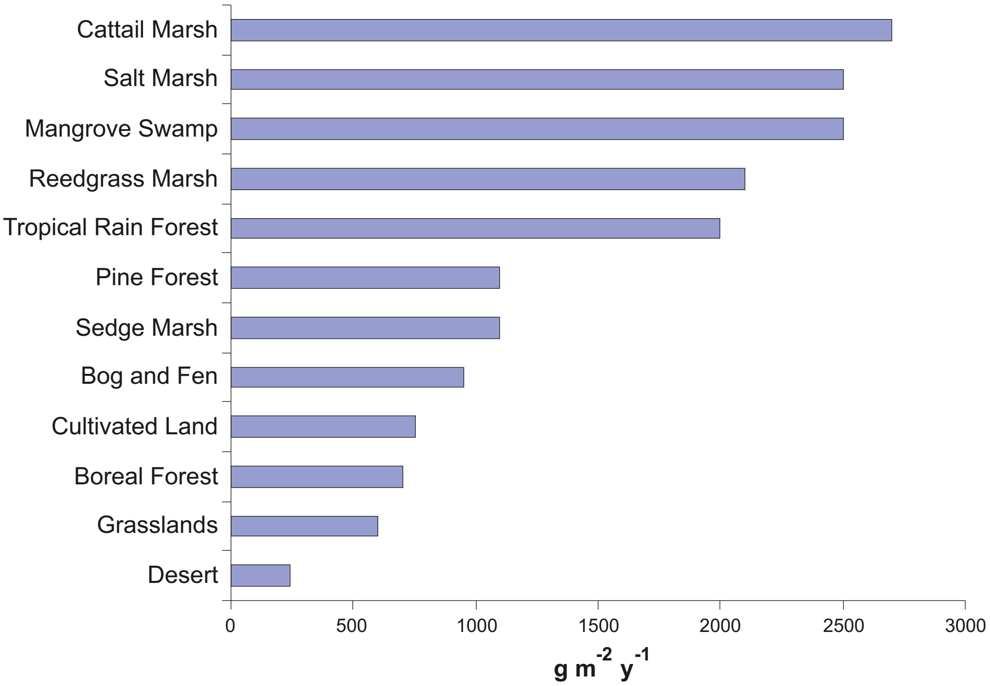

Figure 4-8. *Comparison of net primary production (NPP) between some ecosystem types. From /Richardson 1995/.*

Table 4-5. Calculated biomass and NPP for different wetlands in the Forsmark area and the Laxemar-Simpevarp area. Field and bottom layer data from /Löfgren 2005, Persson and Stadenberg 2007a/ for below-ground biomass converted to carbon assuming a carbon content of 50%. Tree layer descriptions are from /Tagesson 2006a/, but see Section 6.2.2 for detailed information. For wetland types with a tree layer, see also Table 6-10 for more data. See Chapter 6 for a more detailed description of how the values were calculated.

Wetland type (Forsmark/ Laxemar-Simpevarp)	Field and bottom layer		Tree layer	
	Biomass ($gC\ m^{-2}$)	NPP ($gC\ m^{-2}\ y^{-1}$)	Biomass ($gC\ m^{-2}$)	NPP ($gC\ m^{-2}\ y^{-1}$)
Rich fen (Fm)	2,186±1,102	253±59	–	–
Poor fen (Sm)	1,453±419	342±102	–	–
Alnus-spruce swamp (Fm)	68±67	25±22	6,142±2,230	361±124
Alnus shore swamp (Sm)	53±54	50±60	6,428±4,288	224±76

Table 4-6. Estimates of biomass and production in reed stands (*Phragmites australis*). /Alling et al. 2004/ investigated five sea bays, /Andersson et al. 2003/ investigated a lake and /Löfgren 2005/ investigated one sea bay. The carbon content was assumed to be 0.395 /*Scirpus acicularis*, Kautsky 1995/.

	Forsmark	Laxemar-Simpevarp	Other	Reference
Biomass ($gC\ m^{-2}$)	–	2,495±1,353		/Alling et al. 2004b/
	187[1]	–		/Andersson et al. 2003/
	–	1,366±663		/Löfgren 2005/
	–	2,349		/Andersson et al. 2006/
NPP ($gC\ m^{-2}\ y^{-1}$)	–	627±355[2]		/Alling et al. 2004b/
	187[1]	–		/Andersson et al. 2003/
	–	155±117		/Löfgren 2005/
	–	275±151[3]		/Andersson et al. 2006/

1) Only above-ground biomass in late August
2) Only above-ground biomass in July
3) Only above-ground biomass in June

GPP in the field and bottom layer vegetation in a poor fen in the Laxemar-Simpevarp area was estimated to 700 $gC\ m^{-2}\ y^{-1}$ by /Tagesson 2007/, which was high compared to other fen studies in the Nordic countries with values ranging between 250 and 480 $gC\ m^{-2}\ y^{-1}$ /Lindroth et al. 2007/. These ecosystems probably had smaller uptake, since they were situated further north than Laxemar. One of their study sites, Fäjemyren (480 $gC\ m^{-2}\ y^{-1}$), is at a similar latitude as Laxemar, but there are also other factors affecting GPP, such as nutrition, microclimate, biomass, species etc. Assuming that NPP is approximately half of GPP, the two different methods of estimating NPP in the poor fen are in good agreement (350 and 342 $gC\ m^{-2}\ y^{-1}$, Table 4-5).

Soil respiration

Soil respiration is the sum of the respiration from ground vegetation, roots, rhizosphere, mycorrhiza, and microbes. Temperature and moisture are the dominant factors that control soil respiration, and it also varies seasonally /Rayment and Jarvis 2000/. Anaerobic conditions slow the decay rates in wetlands, not only because of a lack of oxygen but also because of low pH, a shortage of calcium, and low soil temperatures. In wetlands where decomposition is fairly high and thereby restricts peat formation, there is a more or less thick humus layer on mineral soil, so they have less carbon in the soil organic carbon pool (SOC) /Lundin et al. 2004/. C-mineralization is the largest flux of carbon leaving the mire, and the difference between litter input and C-mineralization is the accumulation of organic matter. The position of the water table is the principal factor affecting CO_2 fluxes from boreal wetlands /Silvola et al. 1996/, which have consistently shown a strong positive relationship between CO_2 fluxes and water-table depth.

Estimates of wetland forest soil respiration were found to be rather high (Forsmark area, Alnus-spruce swamp SS1 450±380 gC m^{-2} y^{-1} and Laxemar-Simpevarp area, Alnus shore swamp S1 730±620 gC m^{-2} y^{-1}) /Tagesson 2007/ in comparison with estimates for a swampy mixed hardwood stand in the Harvard forest in Massachusetts of 140 gC m^{-2} y^{-1} /Davidson et al. 1998/. Others have found higher values, e.g. 396 gC m^{-2} y^{-1} from May to October 1996 for a boreal black spruce forest in Saskatchewan /Swansson and Flanagan 2001/. /Davidson et al. 1998/ explained their low values not only as being caused by wetness but also due to low input of C to the soil. In the Harvard stand in Massachusetts, trees are sparse so NPP is low as well, whereas at the Forsmark and Laxemar-Simpevarp areas, trees are dense /Tagesson 2006a/, which brings a large carbon input to the soils. Soil respiration in the poor fen in the Laxemar-Simpevarp area (990±1,840 gC m^{-2} y^{-1}) was also somewhat higher than other studies done at mires in the same region. In the Nordic countries, estimated values vary between 214 and 456 gC m^{-2} y^{-1}, where the large values were estimated for Fäjemyren, close to Hässleholm in the southern parts of Sweden and the low values were estimated for Kaamanen in the northern subarctic regions of Finland /Lindroth et al. 2007/.

The anaerobic conditions created in the inundated soil lead to emission of methane and hydrogen gas during decomposition. This emission rate is low compared with the main gaseous product carbon dioxide emitted during heterotrophic respiration (e.g. a boreal bog, 1–2 gC m^{-2} y^{-1} /Alm et al. 1999/ and 4 gC m^{-2} y^{-1} /Waddington and Roulet 2000/). The main determinants of methane (CH_4) emissions from peatlands are water level, temperature, and availability of substrate for fermentation. The highest CH_4 emissions have been measured from wet oligo-mesotrophic fens with abundant sedge vegetation, where annual CH_4 emissions may be over 40 g m^{-2} /Laine and Vasander 1996/. Annual CH_4 emissions from nutrient-poor dry peatlands are less than 10 g m^{-2}. Hardwood-spruce swamps, where the water level is low and moving water has a high oxygen content, may even be sinks for methane, as are mineral soil forests.

There are no estimates of soil respiration in reed belts found around lakes at the sites. However, a model constructed to evaluate the material budget for a reed stand in Austria predicted that between 33 and 48% of the annual above-ground production would decompose within 1 year, while the rest would remain in the anaerobic substrate /Asaeda et al. 2002/. In order to evaluate and calculate the turnover of the BG parts, /Asaeda and Karunaratne 2000/ estimated the annual root mortality to be between 5 and 10% depending on the climate regime.

Transport of organic matter in wetlands

Studies of dissolved organic carbon (DOC) exports to lakes, as a function of vegetation types in a catchment area have shown that wetlands export more DOC than other vegetation types /e. g. Canhem et al. 2004, Humborg et al. 2004/. /Canhem et al. 2004/ calculated the export from temperate conifer wetlands, "emergent marches" and forests to be 17.5 gC m^{-2} y^{-1}, 12.5 gC m^{-2} y^{-1} and 3.5 gC m^{-2} y^{-1}, respectively, using a predictive model based on 2,750 lakes and their catchment areas in Canada. The lateral transport from a boreal bog in Sweden was estimated by /Waddington and Roulet 2000/ to be 4.2 gC m^{-2} and 6.7 gC m^{-2} in two consecutive years.

Export of DOC from terrestrial areas were calculated for Forsmark /Tröjbom et al. 2007/ and Laxemar-Simpevarp /Tröjbom et al. 2008/. Forsmark had a mean export of 2.7 gC m^{-2} y^{-1} for eleven catchments, while the corresponding figure for Laxemar-Simpevarp was 4.8 gC m^{-2} y^{-1} for 14 catchments (See Chapter 8).

An example was calculated to illustrate how much the carbon dynamics within the wetland may be influenced by input of carbon from the local discharge area /Lindborg (ed.) 2005/. This was based on literature data from /Canhem et al. 2004/, who estimated leaching of DOC from conifer forests to be 3.5 gC m^{-2} y^{-1}. The size of the catchment area was multiplied by this figure to get a measure of the DOC load on the wetland. Output from emergent marshes was estimated by /Canhem et al. 2004/ to be 12.5 gC m^{-2} y^{-1}. The results suggested that the average accumulation of external DOC is 4% of the total input from the local wetland to the SOC pool as litter (field layer and roots). /Brydsten 2004/ found that data from six investigated lakes in the Forsmark area suggested that sediments had a high degree of material of autochtonous origin. Several other factors supported this conclusion, such as small topographic variation (small watersheds), low current velocities and low abundance of fine-grained sediments. This pattern suggests that a similar pattern would be likely for wetlands in the Laxemar-Simpevarp area.

Consequently, the external input of DOC from the drainage area is low in relation to the local flux of carbon to the SOC. In the absence of better data it is therefore assumed that the majority of the carbon deposited in wetlands is from production within the wetland.

The pool of soil organic matter and the accumulation of carbon

The net loss or accumulation of organic matter (OM) in a wetland is determined by the balance between the input of organic matter, mainly produced within the wetland, and respiration. The vertical peat growth rate calculated for Finnish mires ranges from approximately 0.2 to over 4.0 mm y^{-1} in some extreme situations /Korhola and Tolonen 1996/. The average value is about 0.5 mm y^{-1}. /Craft and Richardson 1993/ found the build-up of peat to be 1 to 2 mm y^{-1} on average in Everglades peatlands (USA). The peatlands accumulate large quantities of OM since the peat does not decompose and they therefore form an enormous reservoir of terrestrial carbon. In Everglades peatlands, the accumulation rate of organic carbon was measured to be 54 – 161 gC m^{-2} y^{-1}, with an average of 104 gC m^{-2} y^{-1} /Craft and Richardson 1993/. In Finnish mires, the average long-term rate of carbon accumulation show great variation depending on the wetland type, the geographical location, the age of deposit, and the number of fires. In this material, the statistical mean was 19.9 ± 10.7 gC m^{-2} y^{-1}, with a range of 4.6–85.8 gC m^{-2} y^{-1} /Korhola and Tolonen 1996/. The range for the actual accumulation rate was between 8.1 and 23.0 gC m^{-2} y^{-1} (mean 12.1), that is about 2/3 of the long-term rate of carbon accumulation. This suggests that the peatlands in Finland have in general grown to approximately 60–70% of their hypothetical maximal or steady state so far /Korhola and Tolonen 1996/.

For wetlands in the Forsmark area, there are data describing the accumulation of carbon, based on the age of the site (calculated from the height above sea level) and the thickness of the peat layer (Table 4-9), suggesting that wetlands on peat soils accumulate on average 60 gC m^{-2} y^{-1}. Estimates of the long-term carbon accumulation rate were also made using ^{14}C at the bogs Rönningarna in the Forsmark area (38 ± 11 gC m^{-2} y^{-1}) and Klarebäcksmossen in the Laxemar-Simpevarp area (29 ± 4 g gC m^{-2} y^{-1}) /Sternbeck et al. 2006/, which were in the expected range of c 20–50 gC m^{-2} y^{-1} /e.g. Turunen et al. 2002, Malmer and Wallén 2004/. The short-term accumulation of carbon was also estimated using ^{210}Pb at Klarebäcksmossen to 21 ± 0.3 C m^{-2} y^{-1} by /Lidman in manus/, which is in close agreement with the above long-term estimate. Unfortunately, there are few references in the literature describing carbon cycling in forested wetlands, especially fen-like wetlands. However, in comparison with data from /Korhola and Tolonen 1996/, carbon accumulation in mires in the Forsmark area is in the upper range of the long-term rate of carbon accumulation (Table 4-7), which indicates that the mires in the Forsmark area are younger than the average age of the mires investigated in Finland.

The short-term annual accumulation of carbon in a mire can vary considerably depending on the climate /Malmer and Wallén 2004/. The net ecosystem exchange (NEE) during one year was estimated by /Tagesson 2007/ to be between –290 and 320 gC m^{-2} y^{-1}, which shows that there is approximately zero net carbon uptake or loss from the poor fen (see Table 4-46). This is similar to other studies, e.g. in Fäjemyren there is a net uptake of 20 gC m^{-2} y^{-1} /Lund et al. 2007/ and in Kaamanen, Siikaneva and Degerö NEE is between 0 and 30 gC m^{-2} y^{-1} /Lindroth et al. 2007/.

Table 4-7. Estimates of the accumulation rate of carbon in four wetlands in the Forsmark area. The values are calculated using information on the depth of the peat soil and the approximate time since the wetland emerged from the sea, from /Lindborg 2005/. The lower part of the table shows long-term accumulation rates of carbon in Finnish mires from /Korhola and Tolonen 1996/.

Locality	g $Cm^{-2}y^{-1}$	Reference
Forsmark		
Stenrösmossen	43.2	/Fredriksson, 2004/
Lersättermyran	66.3	/Fredriksson, 2004/
T1	58.3	/Lundin et al. 2004/
T2	73.8	/Lundin et al. 2004/
Mean	60.4	
Finnish mires		
Long-term mean	19.9	/Korhola and Tolonen 1996/
Long-term minimum	4.6	/Korhola and Tolonen 1996/
Long-term maximum	85.8	/Korhola and Tolonen 1996/

4.1.2 Agricultural land

Agricultural land is the most intensively managed land in the landscape and is a major provider of food for humans, either directly as crop production or as production of fodder for animals. Agricultural land is the arable land and the pastures or meadows (Figure 4-9, 4-10). The arable land is regularly ploughed and harvested, while the other grasslands are used for livestock grazing or hay-making. Arable land, pastures and semi-natural grassland are all found close to human settlements. The previously extensive semi-natural grasslands and traditionally managed species-rich meadows that have never been ploughed or artificially fertilized have now for the most part been abandoned in keeping with the nationwide general regression of agricultural activities / Eriksson et al. 2002/. Today, a large part of livestock grazing and hay-making takes place in former arable fields with richer soils and higher nutrient content due to fertilization. According to the land use data (Table 4-49, 4-50), the agricultural area in the Forsmark area and Laxemar-Simpevarp areas comprises 84 ha and 1,021 ha, respectively.

Quaternary deposits

The Forsmark area

The largest arable land unit in the Forsmark area is found on clayey till and is located in the southeastern part of the investigation area at Storskäret (Figure 4-10, 4-13). Smaller areas of mostly abandoned arable land are also found in the area. The soil is Regosol/Gleysol, which are less developed sediment soils and clayey till soils of the Cambisol type. This soil type covers arable land, pasture and abandoned arable land /Hedenström and Sohlenius 2008/.

The Laxemar-Simpevarp area

Arable land is situated in the valleys, especially where gyttja clay dominates the floor (Table 4-8). Since the floors of the valleys at many sites are former wetlands, a peat layer covers these sediments in many valleys (see above). The peat layer in these areas is relatively thin and is currently decreasing due to compaction and oxidation as a consequence of draining and ditching. Many areas used as arable land are shown as clay gyttja with a thin peat layer (thinner than 0.5 metre) on the QD map (Figure 3-5). Several of the areas used as arable lands have names ending with “kärret” or “mossen” (fen or bog), which shows that they are former wetlands. The peat in some of the former wetlands has disappeared due to oxidation and Umbrisol/Gleysol has been formed. Umbrisol/Gleysol is the dominant soil type on the fine-grained deposits used as arable land. A large part of the clay areas are, however, not used as arable land, but can be regarded as potential areas suitable for arable land. There are also areas where the type of land use has changed recently. Many small clay and peat areas which are forested today were used as arable land only 50 years ago /Jansson et al. 2004/. The gyttja clay is underlain by post-glacial sand/gravel, which in turn is underlain by glacial clay and till.

Clay gyttja has been deposited in lakes and bays (Figure 4-11). There is no great difference in carbon content between clay gyttja sampled in lakes, fens and bays /Sohlenius and Hedenström 2008/. The highest carbon contents were, however, found in samples from the lakes, where some samples have an organic content of more than 30%. The sediments in the lakes and fens have been deposited both in lakes and bays and show greater variability than clay gyttja from bays, which has been deposited entirely in bays. The clay gyttja in the bays had an organic carbon content between 10 and 20%, whereas one sample analyzed from an area mapped as clay gyttja in the terrestrial parts of the model area had a carbon content of 16%.

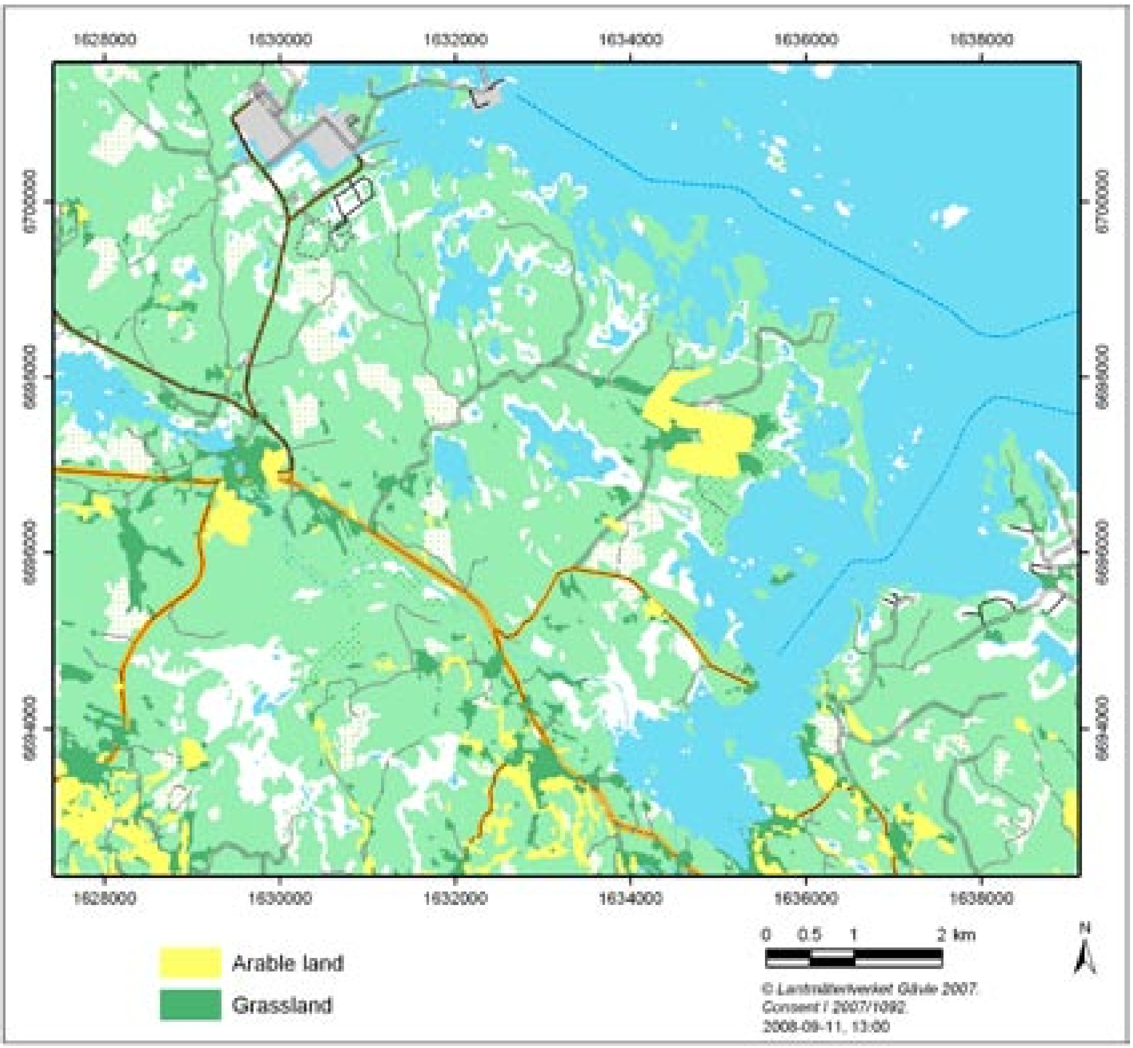

Figure 4-9. *Agricultural land in the Forsmark area, divided into arable land and grassland (pasture and semi-natural grassland).*

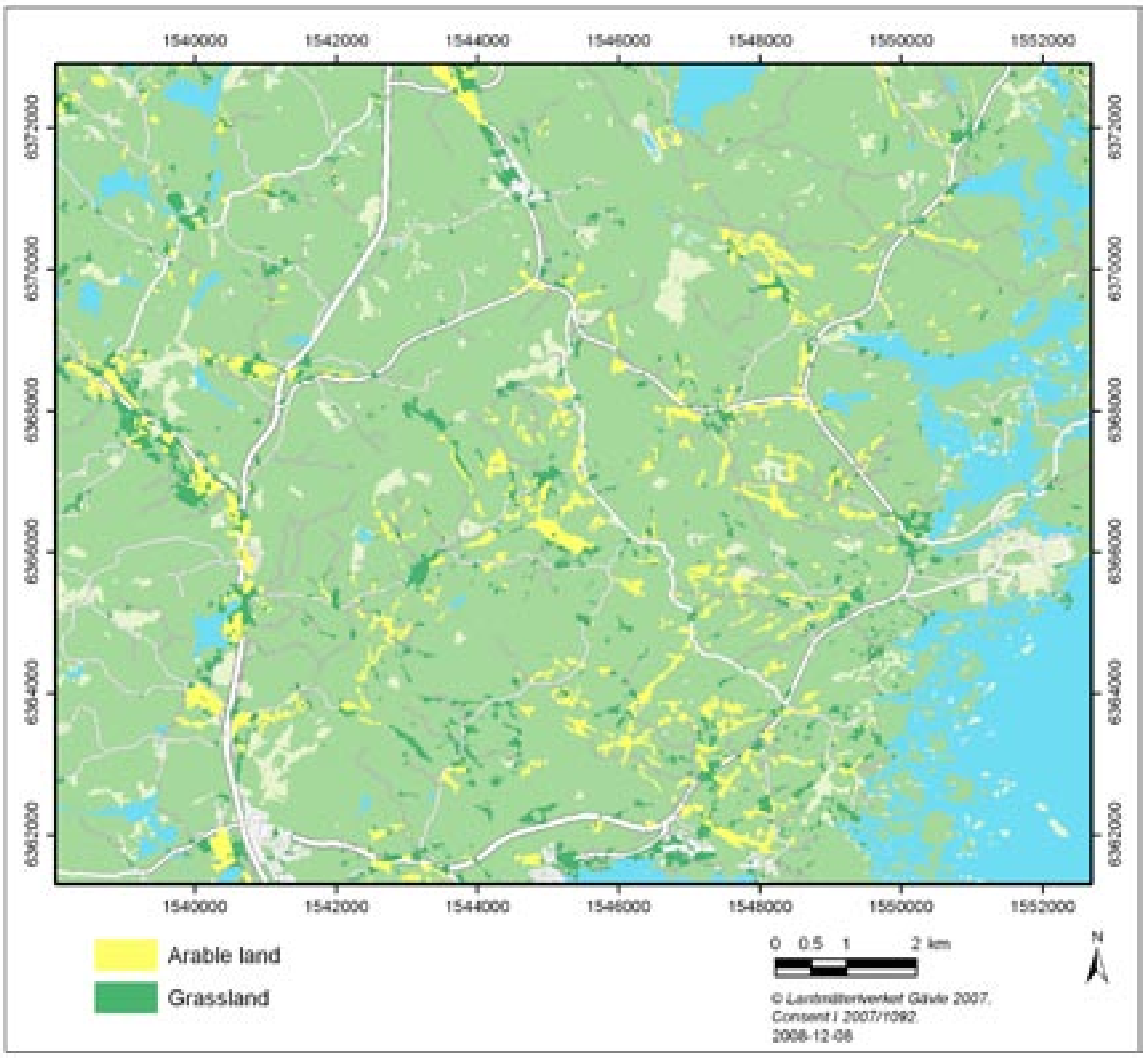

Figure 4-10. Agricultural land in the Laxemar-Simpevarp area, divided into arable land and grassland (pasture and semi-natural grassland).

Table 4-8. The distribution of Quaternary deposits on the areas used as arable land. From /Sohlenius and Hedenström 2008/.

Quaternary deposit	%
Peat	20.6
Clay gyttja	33.9
Gravel	4.4
Sand	22.1
Glacial clay	7.1
Glaciofluvial material	1.2
Till	10.6

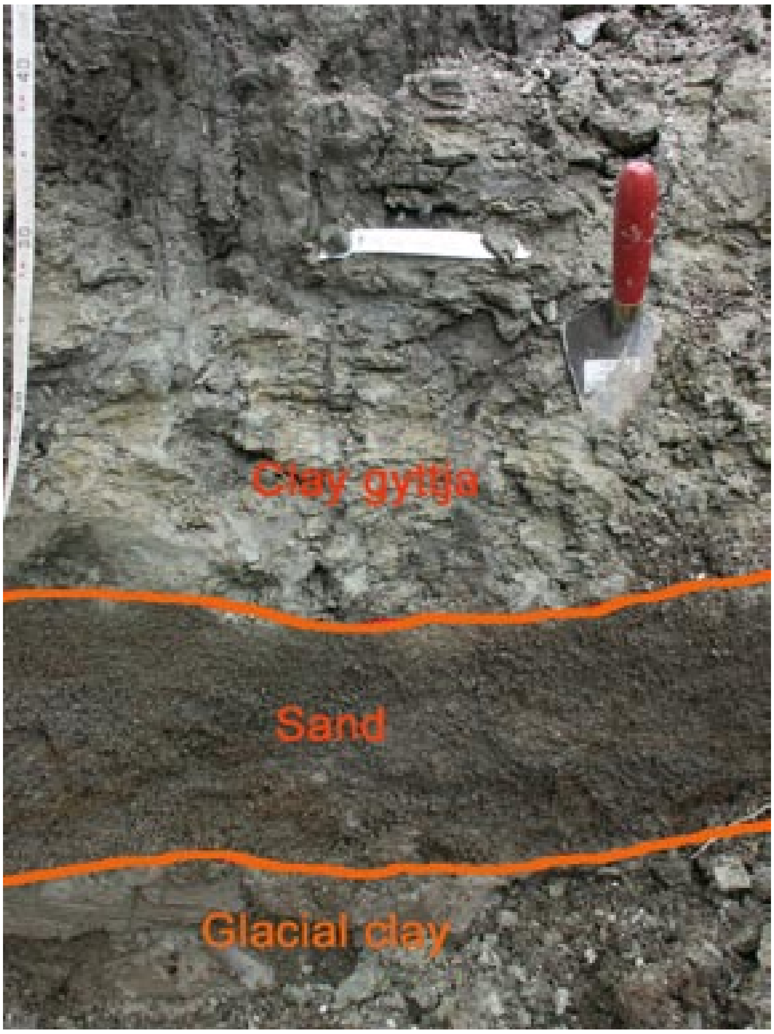

Figure 4-11. Typical distribution of water-laid sediments in the Laxemar-Simpevarp area. The glacial clay was deposited shortly after the last deglaciation. The sand layer represents a long period of erosion by streaming water at the sea floor. The uppermost layer, clay gyttja, was deposited in a sheltered bay. The site is currently used as arable land (PSM007160). Photo: Gustav Sohlenius, SGU.

Surface hydrology

The Forsmark and Laxemar-Simpevarp areas

The land used for agriculture today in the central parts of the Forsmark site investigation area is concentrated to an area covered by clayey till and boulder clay /Hedenström and Sohlenius 2008/. Most of this agricultural land has relatively good natural drainage and no areas have covered drains.

Arable land is often located in low-lying areas where fine sediment or organic soils have been deposited in valleys or depressions /Sohlenius and Hedenström 2007/. Such areas may in many cases be classified as discharge areas, as is the case for the largest arable land unit in the Forsmark area /Werner et al. 2007/. However, most of this agricultural land has relatively good natural drainage and no areas have covered drains. The potential of agricultural land as discharge areas is also emphasized by the thin peat layer associated with arable land in the Laxemar-Simpevarp area /Sohlenius and Hedenström 2007/, which indicates a former wetland stage in many arable land areas. These arable land areas have in most cases been drained in order to lower the groundwater table and make agricultural activities possible. Ditches are characteristically found on agricultural land in both the Forsmark and Laxemar-Simpevarp areas (Figure 4-12). For example, the large arable land unit in the central part of Forsmark has

Figure 4-12. *A drained wetland in the Laxemar-Simpevarp area, where the peat soil has been used for agricultural purposes such as hay making and semi-natural grassland.*

relatively good natural drainage and no areas have covered drains. Neglected management of ditches may cause large areas to become water-logged. Moreover, according to interviews by /Berg et al. 2006/ in the Forsmark area, "bad soils" and the practice of ditching in order to reclaim new land have had the consequence that some of the land, especially the land with organogenic soils, has been compressed, and today these areas are often flooded in the springtime.

Management today

Arable land use in the Forsmark and Laxemar-Simpevarp areas is clearly dominated by production of fodder and grass for domestic animals. Only around 10% of the total agricultural area (arable area and pasture) is used for production of grain and vegetables. According to / Johansson 2005/ the total agricultural area (including imported area) for food consumed in Sweden 1997–2000 was 4 million ha, or 0.44 ha per capita. The dominant crop type was of fodder crops for animal production, which were grown on 74% of the agricultural area. This means that 26% of the agricultural area is used for production of grain and vegetables for human consumption. Accordingly, current land use situation in the Forsmark and Laxemar-Simpevarp areas is more concentrated on production of fodder and grass for domestic animals than the agricultural land area in Sweden in general.

The Forsmark area

The total agricultural area in the Forsmark area is 84 ha (area definition in /Miliander et al. 2004a/), of which 34 ha is arable area and 50 ha is classified as semi-natural grasslands or pastures (Figure 4-13). There is only one farm in the Forsmark area, and it is not possible to obtain crop statistics from SCB (Statistics Sweden) for individual farms. Data for the parish of Forsmark was therefore used to describe the area, according to which only 16% of the arable land area is used for grain and vegetable production, while the rest is used for fodder and silage production (Table 4-9). That corresponds to 6.7% of the total agricultural (field) area in Forsmark parish. The rest of the agricultural area is assumed to be used for fodder production and grazing. A similar relationship between these land use classes in the Forsmark area would suggest that 78.4 ha are used for fodder production and grazing.

The Laxemar-Simpevarp area

Agricultural statistics obtained from SCB for the area (area definition in /Miliander et al. 2004b/) show that 21% of the arable area (138 ha) is used for grain and vegetable production and the rest is used for fodder and silage production (see Table 4-10). The total agricultural area is 1,021 ha, of which 556 ha is arable area and 465 ha is grazing area according to the vegetation map (Figure 3-8). Hence, grain is only produced on 13.5% of the total agricultural (field) area. The rest of the agricultural area is assumed to be used for fodder production and grazing (883 ha). The spectrum of cultivated crops in the Laxemar-Simpevarp area is wide. All the crops grown in the county can also be found in the Laxemar-Simpevarp area except for potatoes, sugar beets and oil seed crops. However, barley is by far the predominant crop in the area, being grown on 66% of the cultivated area (pasture and fodder area excluded).

Figure 4-13. *The largest arable land area, Storskäret, in the southeast of the Forsmark area.*

Table 4-9. Arable land use in the Forsmark parish /Miliander et al. 2004a/.

Cultivated crops in the parish of Forsmark	Average percentage of the arable area (1995+1999)
Grain, vegetables:	
Rye	0.3
Barley	15.6
Oats	0.3
Potatoes	0.2
Total:	**16.4**
Fodder, grass:	
Grass, hay or silage, green fodder	71.8
Pasture/arable land not utilized	0
Pasture, grass land for seed production	9.8
Bare fallow, untilled arable land	2.0
Total:	**83.6**

Table 4-10. Arable land use in the Laxemar-Simpevarp area /Miliander et al. 2004b/.

Cultivated crops in the Laxemar-Simpervarp area	Average percentage of the arable area (1995+1999)
Grain, vegetables:	
Winter wheat	0.8
Rye	1.0
Barley	13.8
Oats	3.5
Triticale wheat, mixed grain	0.6
Leguminous plants	1.8
Total:	**21.4**
Fodder, grass:	
Green fodder, plants for silage	2.2
Grass on arable land for hay or silage	51.8
Pasture, seed lay	12.0
Other plants	0.3
Bare fallow, untilled arable land	10.2
Pasture/arable land not utilized	2.1
Total:	**78.6**

Irrigation and gardening

In Sweden, the portion of the cultivated area that is irrigated is very small, 3–4% /Bergström and Barkefors 2004/. Potatoes and vegetables are the crops that are most often irrigated. According to /Bergström and Barkefors 2004/, approximately 80% of the irrigation water is drawn from lakes and rivers and 15% is groundwater (mostly in Skåne and Halland).

A smaller type of arable land is a garden plot, where vegetables and root crops can be grown for personal use. There are no permanent residents in the Forsmark area, but five summer cottages are situated there. A larger number of both permanent and part-time residents are found in the Laxemar-Simpevarp area. Most of these residents probably have garden plots, but the degree of self-sufficiency in different kinds of crops is not known. Although the extent of irrigation of garden plots is not known, the figures in /Bergström and Barkefors 2004/ indicate a general need in drier summers.

Figure 4-14. *Agricultural land in the central part of the Laxemar-Simpevarp regional model area.*

Seasonal variation

The agricultural land is subjected to different types of changes depending on land use. The pastures and semi-natural grasslands are perhaps less affected by changes in the vegetation and soil, since a major disturbance comes from grazing and trampling by livestock, which may vary from year to year. Grasslands are dominated by perennial herbs and grasses. The arable land is more exposed to seasonal variation due to very short turnover time, i.e. the soil is turned during ploughing, nutrients are added and the vegetation (the crop) is harvested within a year. Ploughing is done in order to loosen up and aerate the soil and to promote the decomposition of the crop residues and thereby promote the release of nutrients. This is done after harvest as a preparation for the next growing period. The vegetation may in some cases be absent during the winter period until the next vegetation period.

Ecosystem properties

The arable land has most of the biomass above ground, and this biomass is regularly harvested, leaving some root litter. Typically, this land is ploughed one or two times each year, creating a more or less homogeneous soil where no humus horizon is found. Fungi are also present in this vegetation type and are known to form mycorrhiza with fertilized crops /Chapin 2002; van der Heijden and Sanders 2002/. All crop root biomass is turned into root litter, since no roots survive until next year because the fields are ploughed during autumn. In the crop production simulations (Chapter 7), 66% of the leaf biomass was removed from the field and 33% remained as litter (Olsson, HIR Malmöhus pers. comm.). It was also shown that root biomass is 19% of the total biomass /Andren et al. 1990/. The grasslands are dominated by perennial plants and have more biomass below-ground, whereas disturbances are more restricted to the above-ground vegetation, such as trampling and grazing by livestock.

Production in grasslands

Historically, the semi-natural grasslands were situated on less fertile land, whereas the fertile land was used for cultivation. This would suggest a lower production in such grasslands. Wet grasslands are more fertile than dry ones and may produce 200 to 240 gdw m^{-2} y^{-1} over long periods as compared with 50 to 60 gdw m^{-2} y^{-1} in a forested grassland /Borgegård 1994/. /Tagesson 2006b/ estimated the NPP for a semi-natural grassland in the Laxemar-Simpevarp area (assuming that NPP is 50% of GPP) to be 270±180 gC m^{-2} y^{-1} using a closed chamber technique along with measurements of air and soil temperature (Table 4-46), while /Löfgren 2005/ estimated NPP to be 273±101 gC m^{-2} y^{-1} using clipping at the time of peak biomass at the same locality (Table 4-16). Seashore meadows have a long history of being used as hay-meadows in the archipelagos and may have high NPP (Figure 4-15). /Wallentinus 1973/ estimated the NPP of a seahore meadow to be between 441 and 594 gC m^{-2} y^{-1} in the southeast Sweden using different approaches (assuming the below-ground production to be twice the above-ground production /Saugier et al. 2001/).

Agricultural products in the Forsmark and Laxemar-Simpevarp areas

Crop production

No site-specific yield statistics are available for crop production in the Forsmark and Laxemar-Simpevarp areas. However, statistics are available describing the standard yields for the yield survey district (SKO area). The Forsmark area is situated in SKO area 0322 and Laxemar-Simpevarp in SKO area 0814 /SCB 2007/. Barley is the predominant grain grown in both the Forsmark and Laxemar-Simpevarp areas. To obtain total crop production, generic values of threshing loss (× 1.05) and straw yield (× 1.4) were added.

The total yield of hay from pastures has been obtained from /SCB 2007/. Hay is the part of the crop that is used as fodder. The amount of carbon in the hay and barley is estimated to be 0.46 gC gdw^{-1}, as for the green field layer in /Fridriksson and Öhr 2003/. The dry weight is 83.5% of the fresh weight of hay and 86% in barley according to /SCB 2007/. The average standard yields are compiled in Table 4-11.

Figure 4-15. *Seashore meadow characterized by a flora typical for localities with calcareous influences in the Forsmark regional model area.*

Table 4-11. Grain production, including threshing loss and straw yield, and fodder production in the yield survey districts, the county and the country.

Standard yield		kg fw/ha Mean	SD	$gC\ m^{-2}\ y^{-1}$ Mean	SD
Grain (barley)[1]	Forsmark in SKO-0322	4,225	94	167	4
	Uppsala County	6,275	192	248	8
	Laxemar-Simpevarp in SKO-0814	4,800	235	190	9
	Kalmar County	5,710	278	226	11
	Sweden	6,184	65	245	3
Hay pastures[2]	Uppsala County			205	12
	Kalmar County			231	31
	Sweden			200	16

[1] (SCB 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007).

[2] Mean value for 2003–2006 from www.scb.se, accessed 4 Dec. 2007.

The productivity of the land in the Forsmark area is significantly lower (approx. 70%) than the productivity of the land in Uppsala County when barley yields are compared. On the other hand, productivity in Uppsala County is above the average yield in Sweden. The production of pastures is roughly equivalent to the average yield in the country.

The productivity of the land in the Laxemar-Simpevarp area is lower (approx. 84%) than the average productivity of the land in the county when barley yields are compared. Barley productivity in Kalmar County is also lower than the average yield in Sweden. On the other hand, the production of hay pastures is greater than the average standard yield in Sweden.

Production during one year on a recently abandoned arable field in Simpevarp was estimated by /Tagesson 2007/, using field measurements and modelling, to be 355±140 $gC\ m^{-2}\ y^{-1}$ (approximately GPP/2, Table 4-46). Other grassland studies have determined a wide range of GPP values between 270 and 1,210 $gC\ m^{-2}\ y^{-1}$ covering both natural grasslands and fields /Flanagan et al. 2002, Suyker and Verma 2001, Suyker et al. 2003, Novick et al. 2004/.

In general, the agricultural area represents a larger part of the Laxemar-Simpevarp area than of the Forsmark area. The standard yields for barley and hay are also higher in the Laxemar-Simpevarp area than in the Forsmark area. The estimate from one year in the field was larger than the SCB statistics. Although the field estimate includes root production, this is not high enough to explain the difference. However, the SCB statistics should be more relevant in describing the long-term production of crops and hay.

Meat, milk and egg production and carbon content

According to the agricultural statistics, there is one agricultural enterprise (farm) in the Forsmark area. This farm has beef cattle. The agricultural land is used for grazing and probably some fodder production. For reasons of secrecy, there are no data concerning production at this single farm. In calculating livestock production in the Forsmark area, the densities of domestic animals in Forsmark parish have been applied to the Forsmark area. Livestock production figures in Forsmark parish and the Laxemar-Simpevarp area are found in /Miliander et al. 2004ab/ along with calculated values of meat production. Meat production is calculated based on the portion of the slaughtered weight that is consumed. A dairy cow produces approximately 7,495 kg milk per year /Miliander et al. 2004ab/. The Forsmark area and the Laxemar-Simpevarp area are defined in /Miliander et al. 2004ab/.

The production figures have been converted to carbon using different sources. The carbon content of mammals is 11.7% of their total (live) weight (44.9% of their dry weight) according to site-specific analysis of the chemical composition of deposits and biota in the Forsmark and Laxemar-Simpevarp areas /Hannu and Karlsson 2006, Engdahl et al. 2006/. The carbon content of milk and eggs can be estimated from their content of proteins, carbohydrates and lipids /Altman and Dittmer 1964, Dyson 1978, Rouwenhorst et al. 1991/:

$$CC_i = 0.53 \cdot \mathit{Proteins}_i + 0.44 \cdot \mathit{Carbohydrates}_i + 0.66 \cdot \mathit{Lipids}_i$$

where CC_i is the carbon content of the i-th food type (kg C/kg fw), $\mathit{Proteins}_i$ is the protein content of the i-th food type (kg/kg fw), $\mathit{Carbohydrates}_i$ is the carbohydrate content of the i-th food type (kg/kg fw) and Lipids_i is the lipids content of the i-th food type (kg/kg fw). The contents of proteins, carbohydrates and lipids in milk (2% milk fat) and eggs (egg 50g, raw) have been found in the Nutrient Database from United States Department of Agriculture /USDA 2007/. The carbon content of milk is estimated to be 5.1% and of eggs 14% .

The production figures have been divided by the total area for grazing and fodder production in Forsmark parish and the Laxemar-Simpevarp area. Production per unit area is shown in Table 4-12 and 4-13. Generally, the density of domestic animals is higher in the Laxemar-Simpevarp area, which is the reason for the higher total meat production. However, total production per unit area is higher in the Forsmark area.

Soil respiration and net ecosystem exchange

Measurements of the CO_2 fluxes revealed that the grassland in the Laxemar-Simpevarp area was a comparatively large net source of carbon during the year when measurements were performed (-324 $g \cdot C \cdot m^{-2} \cdot y^{-1}$ CO_2-C). Net ecosystem exchange was also estimated to be between -660 and -380 $g \cdot C \cdot m^{-2} \cdot y^{-1}$, suggesting that grassland is a net source of carbon. One explanation for this high figure is that the grassland was ditched, suggesting the presence of oxidizing peat soils causing the high negative net ecosystem exchange of CO_2. Two recently abandoned arable fields, one in the Forsmark area and one in the Laxemar-Simpevarp area, showed similar high soil respiration (Table 4-46), but somewhat lower than the grassland. NEE in the agricultural areas indicates that there is net loss of carbon (on average -190 gC m^{-2} y^{-1}) to the atmosphere. Studies in other areas have obtained a wide range of NEE estimates (-950 to 274 gC m^{-2} y^{-1}) /Suyker et al. 2003, Flanagan et al. 2002, Novick et al. 2004, Maljanen et al. 2001, Byrne et al. 2005, Soegaard et al. 2005, Hollinger et al. 2005/.

Interactions with other vegetation types

Agricultural land is often situated on sediments along valleys or in depressions in the landscape. It has often been ditched to some extent in order to lower the water table, thereby optimizing growing conditions. However, these areas may nevertheless be exposed to flooding due to a higher ground water table in the spring and autumn. This process of flooding is further described in Section 4.1.

Table 4-12. Production of animal products (live biomass and utilized meat), milk and eggs in the Forsmark area (average figures for the years 1995 and 1999) presented as carbon per area and year.

Domestic animal	Production (live biomass $mgC \cdot m^{-2} \cdot y^{-1}$)	Meat production ($mgC \cdot m^{-2} \cdot y^{-1}$)	Milk production ($mgC \cdot m^{-2} \cdot y^{-1}$)	Egg production ($mgC \cdot m^{-2} \cdot y^{-1}$)
Beef	1,160	366	7,343	
Sheep	79	18		
Pigs	0	0		
Chicken	93	50		90
Total		**434**	**7,343**	**90**

Table 4-13. Production of animal products (live biomass and utilized meat), milk and eggs in the Laxemar-Simpevarp area (average figures for the years 1995 and 1999) presented as carbon per area and year.

Domestic animal	Production (live biomass mgC m^{-2} y^{-1})	Meat production (mgC m^{-2} y^{-1})	Milk production (mgC m^{-2} y^{-1})	Egg production (mgC m^{-2} y^{-1})
Beef	1,084	342	6,027	
Sheep	17	4		
Pigs	827	353		
Chicken		25		43
Total		**723**	**6,027**	**43**

4.1.3 Forests

Introduction

Forests contain different types of vegetation, all of which have a more or less dense tree cover (> 30%). A forest is often regarded as the climax stage in most parts of the landscape and forest trees are quick to colonize areas previously kept open by human land use. Both sites are found in areas where forest management is intensive.

One important structuring factor in the boreal forests has been the occurrence of fire at various intervals. The fire interval was shorter in areas with shallower soil, so the more fire-tolerant Scots pine is dominant on this less productive soil. More productive and mesic sites are characterized by longer fire intervals and dominated by Norway spruce. Other important disturbances may be insect outbreaks, windstorms and clear-cuts. The spatial scale of these disturbances determines whether they may promote recruitment of new evenly-aged cohorts or multi-aged stand structures. On less fire-prone soils, the gap dynamic is small-scale, and the falling of one or several trees is important for regeneration. Fire has also been an important factor in southern Sweden as forests were often used for shifting agriculture, where areas were cleared, burnt over and then used for sowing crops. These small fields were then abandoned due to a steady decrease in productivity. There was a general trend until the early 20th century for farmland to expand into forested areas. However, as in other developed countries, former agricultural land is now often returned to forest as agricultural production becomes more efficient /Angelstam 1992/. Today, fire has lost its importance in many regions due to efficient fire suppression, but fire does occasionally deforest large areas, resulting in a large turnover of elements previously trapped in the vegetation and soil.

Vegetation

The Forsmark area

Forests cover 73% of the Forsmark land area. The forests are dominated by Scots pine (*Pinus sylvestris*) and Norway spruce (*Picea abies*) situated mainly on wave washed till (Figure 3-1). Spruce becomes more abundant where a deeper soil cover is found along with more mesic-moist conditions (Figure 4-16). Bare rock is not a widespread substrate in the Forsmark area, making pine forest on acid rocks quite scarce. The calcareous soil material provides nutrient-rich conditions, which can be seen in the predominance of humus forms of the mull type and of the intermediate moder type /Lundin et al. 2004/, indicating a rich soil fauna. Because of the young age of the soils, the Forsmark area exhibits less soil of the Podsol type than most similar areas in Sweden. Instead, the typical soil types are the less developed Regosol soils, together with Gleysols and Histosols, which are formed under moist conditions (Table 3-1). The field layer is heavily influenced by its calcareous content and is characterized by herbs and broad-leaved grasses along with a number of orchid species. The deciduous tree species are dominated by *Betula pendula, Alnus glutinosa* and *Sorbus acuparia*, but *Acer platanoides* and *Fraxinus excelsior* are also fairly common. Especially *F. excelsior* may be abundant along sheltered seashores. *Quercus robur* and *Ulmus glabra* are close to their northern limit and are therefore scarce.

Figure 4-16. *Herb-rich Norway spruce forest in the Forsmark area.*

The Forsmark area has a long history of forestry, which is seen today in a fairly high frequency of younger and older clear-cuts in different successional stages in the landscape. *Betula pendula* is the dominant species in many of the earlier successional stages until it is replaced by young Norway spruce or Scots pine depending on soil type and/or management.

The Laxemar-Simpevarp area

Forests cover 86% of the land area in Laxemar-Simpevarp (Figure 3-8). The forests are dominated by Scots pine (*Pinus sylvestris*) situated on bedrock or nutrient-poor thin soils with shrubs, mostly *Calluna vulgaris*, grasses such as *Deschampsia flexuosa, Agrostis vinealis* and *Festuca ovina*, and lichens and mosses on the ground layer. When these pine forests get moister, *Vaccinium vitis-idaea* and *Vacinium myrtillus* become more common in the field layer. Norway spruce (*Picea abies*) becomes abundant where a deeper soil cover is found, while deciduous tree species are more common near the coast, i.e. mainly *Quercus robur* but also *Corylus avelana*, *Sorbus aucuparia, S. intermedia* and *Acer platanoides*, making the mixed forest the second most common forest type. *Q. robur* is often the dominant tree species when more or less pure deciduous forests are found (Figure 4-17). The character of these forests is a function of boulder frequency, nutrient availability and earlier history of management. The predominant humus form is moder in Scots pine and Norway spruce forests, where Regosol dominates but Podzol becomes more common where there is a deeper soil cover. The mull-like humus form is more dominant as deciduous trees becomes more prevalent /Lundin et al. 2005a/ and here the soil types Regosols and Umbrisols are found (Figure 3-6).

There are areas where land use has changed rather recently. Many small clay and peat areas which are forested today were used as arable land only 50 years ago /Jansson et al. 2004/. The soil properties in such areas are probably greatly affected by that former land use. The Laxemar-Simpevarp area has a long history of forestry, which is seen today as a fairly high frequency of younger and older clear-cuts in different successional stages in the landscape. *Betula pendula* is the dominant species in many of the earlier successional stages until it is replaced by young Norway spruce or Scots pine depending on soil type and/or management.

Figure 4-17. *Deciduous forest with Acer platanoides, Tilia cordata and Quercus robur on bouldery ground in the Laxemar-Simpevarp regional model area.*

Surface hydrology

The Forsmark area

Due to the flat terrain and the shallow groundwater levels, there is a strong interaction between evapotranspiration, soil moisture and groundwater. The groundwater levels in many monitoring wells in Quaternary deposits were less than one metre below ground all year, and the groundwater level on average was less than 0.7 m below ground 50% of the time. Even in what can be considered as typical recharge areas, the average groundwater level was not more than 1.2 m below ground. It is only in locally elevated areas with relative steep slopes that groundwater levels can be assumed to be considerably deeper. The annual variation in the groundwater level is mostly less than one metre in discharge areas, and 1.5 m in typical recharge areas. Diurnal fluctuations of the groundwater levels, driven by evapotranspiration cycles, were evident in the data from many of the groundwater monitoring wells in Quaternary deposits /Johansson 2008/.

Due to the small-scale topography and the hydraulic conductivity profile of the tills that dominate in the area, many small catchments are formed with local shallow groundwater flow systems in the Quaternary deposits, and most of the groundwater moves along these shallow flow paths. During periods of abundant groundwater recharge, the groundwater level, even in most recharge areas, reaches the shallow part of the Quaternary deposit profile where the hydraulic conductivity is much higher and a significant lateral groundwater flow takes place. However, the transmissivity of this upper layer is so high that the groundwater level does not reach much closer to the ground surface than 0.5 m in typical recharge areas /Johansson 2008/.

Direct recharge from precipitation is obviously the dominant source of groundwater recharge. However, the groundwater level measurements in the vicinity of Bolundsfjärden and Eckarfjärden show that the lakes may act as recharge sources for the till aquifers in the immediate vicinity of the lakes in the summer. While the groundwater levels are well above the lake water levels for most of the year, they are considerably below the lake water levels under dry summer conditions. This is very clear close to the lake shores, but even in the middle of the lakes the groundwater levels are slightly below the lake levels under such conditions (the difference is well outside the probable measurement error). The gradients from the lakes to the surrounding areas are created by direct and indirect groundwater abstraction caused by evapotranspiration. However, due to the low permeability of the bottom sediments, the resulting water fluxes can be assumed to be relatively small /Johansson 2008/.

The Simpevarp-Laxemar area

Groundwater levels in the Quaternary deposits are shallow; according to monitoring data, on average the depth to the groundwater level is less than c 1 m during 50% of the time. Generally, there is a larger depth to the groundwater level in high-elevation areas compared to low-elevation areas. However, there is a much smaller range of depths to the groundwater level compared to absolute groundwater levels. There is hence a close correlation between the ground-surface topography and groundwater levels in the Quaternary deposits, which in turn implies that topography has a strong influence on near-surface patterns of groundwater recharge and discharge /SKB 2009/. According to the conceptual hydrogeological model, groundwater recharge primarily takes place in high-altitude areas, dominated by outcrop rock or shallow regolith depths. Groundwater recharge also takes place within the ”hummocky moraine” and ”glaciofluvial deposits” type areas, characterised by smaller-scale topography and eskers, respectively /SKB 2009/.

Regolith

The Forsmark area

Till is the dominant Quaternary deposit that fills small crevasses in the bedrock, dominated by granite (Figure 3-1). The shoreline of northern Uppland is characterized by a high frequency of boulders from the till. Glacial till is the dominant Quaternary deposit in the Forsmark area, covering 65% of the terrestrial areas. One main characteristic of the till in the Forsmark area is the generally high calcium carbonate content of the fine and gravel fractions of the till.

The dominant soil types are Regosols and Gleysols (Figure 3-2, Table 3-1), which are formed on unconsolidated course-textured parent material and are characterized by a minimal soil profile development as a consequence of young age. Humus forms are mor or moder. Typical soils for Sweden are Podsols but this soil type has not yet developed at Forsmark. This poor soil development is a result of young age.

The Laxemar-Simpevarp area

The regolith in the topographically high areas is generally one or a few metres thick and is completely dominated by forest. The soils in till areas with coniferous forest are dominated by Podzol and poorly developed soils (Table 3-4). The most high-lying areas, which are mainly found in the northern part of the regional model area, are dominated by bedrock with a more or less thin soil layer. In till areas with deciduous forest, Umbrisol and poorly developed soils, Regosol, dominate. The frequent occurrence of Regosol shows that the soil-forming processes have not been active long enough to form distinct soil horizons at all investigated sites. The Laxemar-Simpevarp area is completely situated below the highest coastline and many of the investigated sites have consequently only been subjected to soil forming processes for a few thousand years /Sohlenius and Hedström 2008/.

The areas covered by wetlands have diminished significantly, due to the lowering of the groundwater table by ditches. That was done for agricultural purposes (see Section 4-2), but also to improve the rate of forest growth (Figure 4-18). The soils in the present and former wetlands are dominated by Histosol. The peat in some of the former wetlands has been reduced due to

***Figure 4-18.** Ditching to promote forest growth in the Laxemar-Simpevarp area.*

oxidation and Umbrisol/Gleysol has been formed. It was concluded that forest areas covered by peat are underestimated in the peripheral parts of the investigation area, where aerial photos have been used to determine the spatial distribution of peat. Such peatlands are often difficult to recognize in the aerial photos, especially at sites where the groundwater level has been lowered by ditches /Sohlenius and Hedström 2008/. For example, a peat area covering several hectares west of Gästern, not shown on the QD map (Figure 3-5), was found during a field check. Such areas have often been above sea level for a too short period for a distinct peat layer to form.

The soil contents of different elements were in a similar range as in other studies, but deviated from the large-scale soil contents in Sweden where the forested till soils provide poorer conditions. At the sites investigated here, the arable and pasture lands provide comparably nutrient-rich conditions. For a thorough description of the soil chemistry investigation, the readers are referred to /Sohlenius et al. 2006a/.

Management today

The forests in the Forsmark and Laxemar-Simpevarp areas are mainly owned and managed by Sveaskog AB. The forest holdings of Sveaskog are managed according to the policies and standards in Forest Stewardship Council (FSC). FSC provides guidelines for environmentally appropriate, socially beneficial and economically viable forest management. The long-term ambition of Sveaskog is to achieve nature conservation areas covering 20% of the productive forest land. This will be achieved by developing so-called ecoparks and through the creation of nature reserves. According to /Sveaskog 2007/ the forests are managed over their life-cycle based on the descriptions of the different phases of management given below.

Soil preparation

To improve the opportunities for new plants or seeds to become established, a clear-cut area is normally scarified so that some of the mineral soil is laid bare by removing the field and ground layers.

Forest regeneration

70% of the forest area is on average regenerated by plantation, 20% by natural regeneration (with seed trees) and 10% by sowing. Natural regeneration is mainly used in Central Sweden, on poor and coarse soil with less competition from other vegetation. It is not a potential alternative in northern Sweden, due to a colder climate, or in southern Sweden where the soil is normally very fertile. Plantation is preferred when soil fertility is good. Pine is generally used for natural regeneration and sowing. Regeneration must take place within three years after clear-cutting.

Forest clearing

Forest clearing is carried out when the spruce trees are 2–4 metres tall and the pine trees are 4–5 metres tall . It can be done earlier if herbivory by moose is negligible. Unwanted trees, such as damaged trees and trees that are standing too closely together, are cut down. The trees are not removed from the site as in the case of thinning, but are left to decompose.

Forest thinning

Forest thinning is normally performed when the forest is 30–50 years of age. On the most fertile soils, thinning is done three times before clear-cutting, while once or twice is sufficient on poorer soils. At most 30–35% of the timber volume is generally removed by thinning. The remaining trees benefit from the increased availability of light, nutrients and soil water following thinning.

Forest fertilization

Nitrate fertilizers are often added to soils of medium quality. This is not profitable on poor soils or on fertile soils. It is most cost-effective to fertilize the forest about ten years before clear-cutting.

Clear-cutting

The forest is finally cut down at the age of approximately 100 years. On the most fertile soils in southern Sweden, the forests reach a mature age for cutting much earlier, after 45 years of growth at the earliest. The quality, timber volume, dimension and age of the forest determine when the forest is mature for cutting. Clear-cutting without natural regeneration entails that all trees are felled, except old trees (so called nature value trees), high stumps and some smaller groups of trees.

Ecosystem properties

The forest at both sites consists of different vegetation with different inherent properties with regard to different aspects of element accumulation and cycling, e.g. standing biomass and NPP may differ between different forest types. A number of field studies have addressed questions with the aim of describing the range of these properties at the sites.

Tree stand description

An ongoing monitoring project, the National Forest Inventory /Anon 2002/, has done extensive field work covering the whole of Sweden. SKB has been able to use a subset of this database /*http://www-riksskogstaxeringen.slu.se/*, covering the period between 1985 and 2005, in order to describe forests at the sites. A regional area was defined and data from their subplots was extracted according to specified criteria (classified as forest land, age above 10 y, inventoried between 2000 and 2005 and having a tree biomass above 0) (Table 4-14).

Table 4-14. Description of different properties of forests in the Forsmark and Laxemar-Simpevarp areas using information extracted from the NFI database from a larger region around the sites. Mean ± standard deviation.

Properties	Forsmark area	Laxemar-Simpevarp area
Tree biomass (gC m^{-2})*	7,650±4,362	6,616±4,560
Stem increment (gC m^{-2} y^{-1})	131±87	133±98
Age (year)	65±33	60±39
Number of plots	228	155

*Whole tree except fine roots (< 5 cm) and leaves of deciduous trees.

/Abrahamsson 2003/ and /Andersson 2004/ performed measurements of a number forest parameters, such as height and diameter at breast height, in order to describe production at the Forsmark and Laxemar-Simpevarp areas. These investigations were focused on certain vegetation types and cannot be regarded as a representative subset of the forests describing the whole site. In both the Forsmark and Laxemar-Simpevarp areas, Scots pine was the dominant tree in the tree layer in most of the investigated areas. /Tagesson 2006a/ also published descriptions of stand volume and stand breast height age for a number of forest plots in the Forsmark area (3) and the Laxemar-Simpevarp area (9) that were used in his work of describing leaf area index at the sites. His estimates represented mature forests and were therefore higher than the values in Table 4-14.

Field, bottom and litter layers

/Löfgren 2005/ estimated the biomass in the field, bottom and litter layers and net primary production (NPP) in the field and bottom layers in a number of vegetation types in both the Forsmark and Laxemar-Simpevarp area, by collecting the standing crop at the peak of the biomass in one year. Below-ground estimates of roots were corrected for tree roots when a tree layer was present in the investigated vegetation type. The overall most productive field and ground layers were found in the vegetation types lacking a tree layer, such as the mire or the grassland (Table 4-15, 4-16). These were also the habitats that displayed the highest biomass values. The lowest NPP was found in the forested wetland and the coniferous forest.

The amount of litter was highest in the spruce forest (highest in the Laxemar-Simpevarp area and second highest in the Forsmark area) (Table 4-17, 4-18). The vegetation type with the lowest amount of litter was mire.

Although the variation in estimated parameters was relatively large, the results agree fairly well with other investigations at a similar latitude /Fridriksson and Öhr 2003, Berggren et al. 2004/.

Table 4-15. The mean biomass and NPP of the field and ground layers for the investigated vegetation types in the Forsmark area. Biomass value in unit gdwm^{-2} and NPP in unit gdw m^{-2} y^{-1}. The standard deviation is presented after the mean and the range is presented below the mean.

Parameters	Mire	Forested wetland	Herb dominated moist soil	Grassland	Coniferous forest	Thin soil
Biomass	4371±2203	295±109	225±108	833±186	503±203	1141±387
	2718-7816	180-471	118-392	659-1147	219-720	715-1697
NPP	505±118	32±25	195±106	825±246	137±78	465±335
	353-678	2-65	98-350	538-1129	34-223	109-1012

Table 4-16. The mean biomass and NPP of the field and ground layers for the investigated vegetation types in the Laxemar-Simpevarp area. Biomass value in unit gdw m^{-2} and NPP in unit gdw m^{-2} y^{-1}. The standard deviation is presented after the mean and the range is presented below the mean.

Parameters	Mire	Forested wetland	Herb dominated moist soil	Grassland	Coniferous forest	Thin soil	Shore
Biomass	2905±837	685±696	405±255	968±342	668±296	627±69	2628±1300
	1744-3991	44-1834	200-842	653-1517	392-1030	553-705	1125-4365
NPP	683±403	86±84	277±71	545±202	101±55	94±34	310±314
	303-1367	34-234	213-396	268-792	44-182	56-142	55-753

Table 4-17. Litter layer described in the Forsmark area. Standard deviation is presented after the mean and the range is presented below the mean. All numbers have the unit gdw m^{-2}.

Parameters	Mire	Forested wetland	Herb dominated moist soil	Grassland	Coniferous forest	Thin soil
Weight	539±212	698±277	1081±861	980±286	1042±488	595±430
	369-791	339-1093	133-2119	639-1431	408-1704	164-1163
Content Dominating component	*Carex, Phragmites australis*	Leaves and branches (*Betula*, *Alnus* etc.)	Leaves, grass	*Elymus repens*	Neddles *(Picea abies)* and grass	Neddles and branches *(Pinus sylvestris)*

Table 4-18. Litter layer described in the Laxemar-Simpevarp area. The standard deviation is presented after the mean and the range is presented below the mean. All numbers have the unit gdw m^{-2}.

Parameters	Mire	Forested wetland	Herb dominated moist soil	Grassland	Coniferous forest	Thin soil	Shore
Weight	272±197	1084±248	489±169	486±449	1595±1083	1216±543	700±305
	71-517	814-1331	319-665	131-1264	501-2860	461-1782	234-1034
Content Dominating component	*Carex, Equisetum*	Leaves *(Alnus glutinosa)*	Leaves *(Quercus robur)*	Grass	Neddles, cones, branches *(Picea abies)*	Neddles, thin bark *(Pinus sylvestris)*	Parts from *Phragmites australis*

Birch on clear-cuts

Clear-cuts are rather common in both investigation areas, due to the high amounts of commercial forests. After a clear-cut, a dense birch forest (*Betula pendula* and *B. pubescens,* where *B. pendula* dominates) is allowed to emerge, which partly serves as a protection for the next generation of planted coniferous trees. /Alling et al. 2004c/ attempted to quantify the biomass and net primary production (NPP) of this successional stage now commonly used in the forestry management at both sites. Five localities were censused at each site. Using functions from already published work, the biomass were calculated for stem, living and dead branches /Marklund 1988/, coarse roots /Alexeyev et al. 1994/ and fine roots /DeAngelis et al. 1981/ and leaves separately. Net primary production was calculated using the annual diameter increment, estimated from annual rings, and the biomass functions.

The median total biomass was estimated to be 494 gC m^{-2} and 583 gC m^{-2} for the Forsmark and Laxemar-Simpevarp areas, respectively. The median NPP was estimated to be 162 gC m^{-2} y^{-1} and 213 gC m^{-2} y^{-1}, respectively. The higher values in the Laxemar-Simpevarp area were attributed to higher number of stems per m^2. The annual increment of the birch stems was surprisingly similar between localities and sites (0.18 cm y^{-1} ± 0.04, N=10) /Alling et al. 2004c/.

LAI

Leaves are the surface where an exchange of matter and energy between the atmosphere and the biosphere takes place. The leaf area index (LAI), expressed as the leaf area projected onto a horizontal plane, of the vegetation cover is correlated with a number of ecophysiological parameters, such as net primary production (see Chapter 7), transpiration and intersection of water in canopies. An LAI map covering an area will therefore constitute an important input to the description of production and regional water balance.

In the investigation areas, the LAIs of coniferous and deciduous tree ecosystems were estimated indirectly through optical measurements using LAI-2000 (LI-COR, Cambridge UK) and TRAC (Tracing Radiation and Architecture of Canopies) /Tagesson 2006a/. On average, measured maximum LAI was 3.40 in the Laxemar-Simpevarp area and 3.43 in the Forsmark area; minimum LAI was 1.65 in the Laxemar-Simpevarp area and 1.97 in the Forsmark area. Forest inventory data showed that LAI was positively correlated with basal area, stand height, stand volume and breast height tree diameter. For the coniferous stands, there was also a linear negative relationship with age, which means that older trees get a lower LAI. LAI was correlated with the normalized difference vegetation index (NDVI) in the Laxemar-Simpevarp area, while in the Forsmark area effective LAI was correlated with NDVI. These correlations made it possible to use NDVI images to construct LAI maps for each site (Figures 4-19 and 4-20).

Above-ground litterfall and decomposition

/Mjöfors et al. 2007/ studied litterfall from trees and the decomposition of litter at three localities at both sites (Table 4-19). The sites were chosen in order to complement the other investigations at those sites describing different pools and fluxes of organic matter. The abbreviations in the text below follows those stated in Table 4-19.

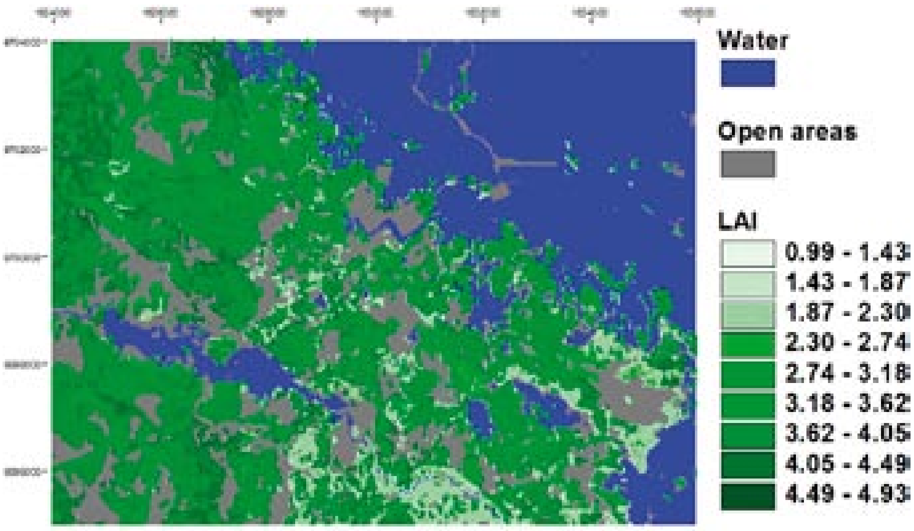

Figure 4-19. *NDVI modelled LAI for the Forsmark area from /Tagesson 2006a/.*

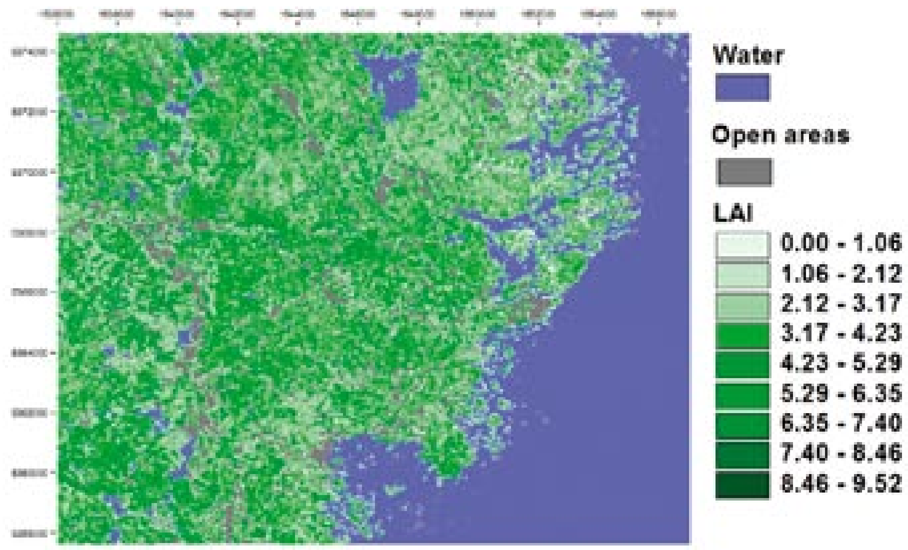

Figure 4-20. *NDVI modelled LAI for the Laxemar-Simpevarp area from /Tagesson 2006a/.*

Table 4-19. The forest stands that were studied with regard to litterfall in the Forsmark and the Laxemar-Simpevarp areas. The stands are identical with the ones described by /Lundin et al. 2004, 2005a/ in the characterization of soils.

Site	Forest type	Id in /Mjöfors et al. 2007/	Id in /Lundin et al. 2004, 2005/	X- koord.	Y- koord.	SKB id-codes
Forsmark	Norway spruce	F1	FG1	6698152	1633558	AFM001068
	Norway spruce/Alder	F2	SS1	6698060	1633495	AFM001076
	Norway spruce	F3	B2*	6698733	1633420	AFM001247
Simpevarp	Common Oak	O1	Löv 1	6367828	1552003	ASM001426
	Scots pine	O2	Häll 1	6367322	1552510	ASM001428
	Norway spruce	O3	Gran 1	6369225	1547128	ASM001440

*The site was moved about 300 m from that one described by /Lundin et al. 2004/, denoted AFM001066.

Above-ground litterfall

Annual litterfall from trees was measured from June 2004 to June 2006 using litter traps. The above-ground litterfall in the Forsmark and Laxemar-Simpevarp areas (Figure 4-21) was within the range (120 to 452 gdw m^{-2} y^{-1}) reported by /Berg et al. 1999a/ for Norway spruce stands located from the Arctic Circle in the north of Sweden to the latitude of Malmö in the south. The proportion of needles/leaves in the total litterfall varied between 65% and 75% in the studied stands.

The carbon returned in above-ground litterfall amounted to between 60 and 110 gC m^{-2} y^{-1} in the forests in the Forsmark area. Corresponding figures for the forests in the Laxemar-Simpevarp area were 70 to 190 gC m^{-2} y^{-1}. At site O3 the litterfall was markedly higher during the first year of measurement than during the second (a difference of about 170 gC m^{-2}). This between-year variation in litterfall may have been the result of the storm 'Gudrun', which hit Götaland in January 2005 and partly affected the Laxemar-Simpevarp area. During the first year of measurement, a slightly higher litterfall was also observed in the pine stand (O2), but not in the oak stand (O1). The lack of increase in the later stand was probably due to the fact that the oak trees were already defoliated when the storm came in January. Although the between-year variation in litterfall can be very high due to fluctuations in environmental factors, it was rather low in both areas investigated in this study. The ratio of maximum to minimum annual total litterfall within a site ranged between 1.2 and 1.6. These values are somewhat lower than those reported by /Berg et al. 1999a/ for 12 stands located from Norrbotten in the north of Sweden to Blekinge in the south, where total litterfall was measured during 4 years. The ratios observed ranged between 1.1 and 2.1. This indicates that above-ground litterfall has to be monitored over several years to get a high accuracy in the estimates. The high litter production at site O3 compared with site F3 can probably be explained by fertility differences between the sites. Site O3 is a drained peatland with spruce on a fresh to fresh-moist soil. These kind of soils can provide high yields /Lundin et al. 2005/ and thus have a high litter production. Site F3, on the other hand, is a poorer and less productive soil, which can explain the low litterfall at the site. The litterfall produced in the Scots pine stand at site O2 within the Laxemar-Simpevarp area (about 150 gdw m^{-2} y^{-1}) is also within the range (74 to 420 gdw m^{-2} y^{-1}) reported for Scots pine stands in Sweden /Berg et al. 1999b/. However, it is lower than for pine stands of 'normal fertility', which generally have a litter production of around 300 gdw m^{-2} y^{-1} /Berg et al. 1999a/. The Scots pine stand at site O2 was growing on a soil of lower fertility (coarse sandy and sandy-silty till cover of 0.3–1.0 m /Lundin et al. 2004/) and had a low stem density, resulting in a low basal area, which in turn gives rise to a low litter production /Berg et al. 1999b/.

At sites O1 and O3 in the Laxemar-Simpevarp area, about 3.6 gN m^{-2} y^{-1} of N was returned annually to the forest floor by the above-ground litterfall. This was four times more than the N deposited in the Scots pine stand (O2) in the same area (about 0.8 gdw m^{-2} y^{-1}). In the Forsmark area, the N return in litterfall varied between 1.1 and 2.6 gdw m^{-2} y^{-1}, the lower figure for site F3

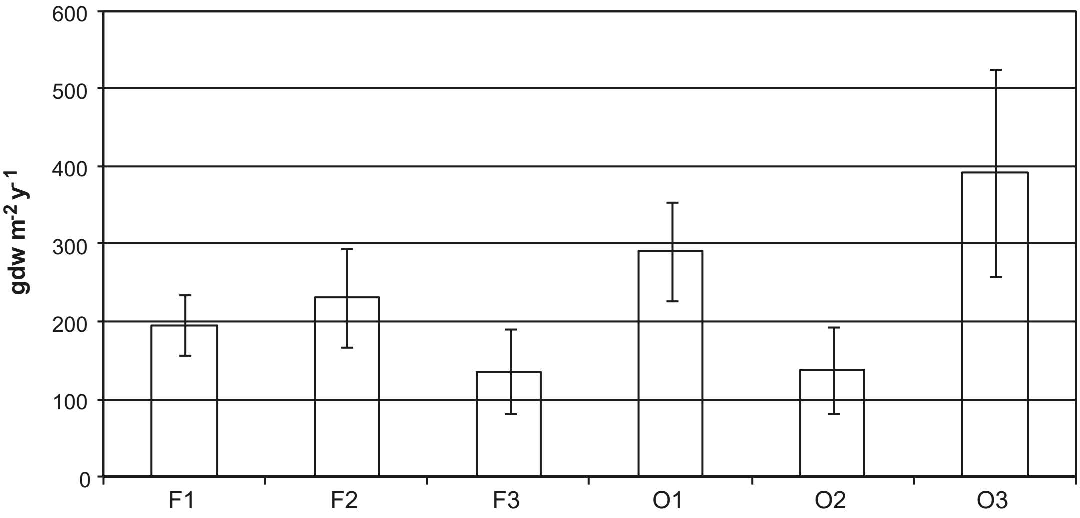

Figure 4-21. *Mean annual total litterfall with standard deviations. F denote the investigated Forsmark localities, whereas O denotes the localities in Laxemar-Simpevarp. Abbreviations on the x-axis follow the ID codes in Table 4-19. Data from /Mjöfors et al. 2007/.*

and the higher for site F2. At site F1 about 1.7 gdw N m^{-2} y^{-1} was deposited. Although the difference is great, the figures are in agreement with results from other studies. /Lundmark et al. 1982/ reported an N return of 0.6 gN m^{-2} y^{-1} in relatively young Scots pine stands located in Central Sweden. /Lundmark 1988/ found (as a mean for five middle-aged stands) that 0.8 gN m^{-2} y^{-1} was deposited with the needle fraction. Furthermore, /Johansson and Lundmark 1986/ and /Johansson and Grälls 1989/ reported an N return of 3.2 to 6.2 gN m^{-2} y^{-1}. That site F2 consists of a mixed spruce/alder stand is evident from the size of the N return in litter. It is much lower than the figure reported by /Johansson and Grälls 1989/ for a pure alder stand (6.6 compared with 2.6 gN m^{-2} y^{-1}).

Decomposition of above-ground litterfall

The decomposition of the site's "own" litter was followed for two years and was predicted for up to 10 years with a dynamic decomposition model /Ågren and Bosatta 1998/. Litterbags containing dried leaves/needles of known weight were put on the ground. Three times a year, one litterbag was collected from each of 25 subplots in the six localities and a weight loss was calculated after the second weighing.

In all three stands in the Forsmark area, the spruce needle litter lost around 33% in mass during the first year, and after two years the accumulated mass loss amounted to 45%. The alder leaf litter decomposed more rapidly and lost 60% in mass during the first year and had reached an accumulated mass loss of 73% after the two years. The extremely high mass loss rate shown by the alder leaf litter was probably due to a favourable chemical composition that promoted decomposition. High N and calcium (Ca) contents in litter are known to stimulate the decomposing microorganisms /Yamaya and Branch 1968/. In general, minor differences were noted in the decomposition pattern for the spruce and pine needles within the Laxemar-Simpevarp area. The pine needles started to decompose at a somewhat lower rate than the spruce needles (16% compared to 18% during the first 77 days), but after two years the pine needles had lost significantly more in mass than the spruce needles (52% compared to 46% for spruce needles), which is a well known phenomenon /Johansson et al. 1986, Berg et al. 1996/ and has been ascribed to a lower concentration of lignin and a higher concentration of ethanol-solubles in pine needles than in spruce needles. Thus, the oak and pine litters had lost about half of their initial mass (51 to 52%) and the spruce litter a somewhat smaller fraction (45%) during two years of decomposition. According to the model predictions, about 80% of the initial mass would have decomposed in needle litters and oak leaves after 10 years, but over 90% the initial mass of alder leaves was predicted to have decomposed.

Mineralization of N started immediately from alder leaves and proceeded at a fast rate for the first five months, after which it slowed down markedly. In general, about 80% to 90% of the initial N amount still remained in the litter after two years of decomposition (100% in the pine needles), whereas alder leaves had lost 60% of their N.

The release of P started immediately from all litter types and was most rapid from the alder leaf litter, which lost about 60% of its initial amount during the first five months. The other litter types generally lost around 10–20% within the same time period. However, oak leaves and the spruce needles at sites O1 and O3 in the Laxemar-Simpevarp area exhibited higher losses (30–40% of initial amount).

According to the model predictions (Figure 4-22), after 10 years of decomposition about 60–70% of the initial nitrogen and 80 to over 90% of the initial phosphorus would be released from the spruce needles and the oak leaves. Markedly lower releases of nitrogen and phosphorus were predicted for pine needles, 54 and 41%, respectively. The release rate of nitrogen and phosphorus from alder leaves was predicted to be very high and only a few % of the initial nitrogen and phosphorus was predicted to remain in alder leaves after 10 years of decomposition.

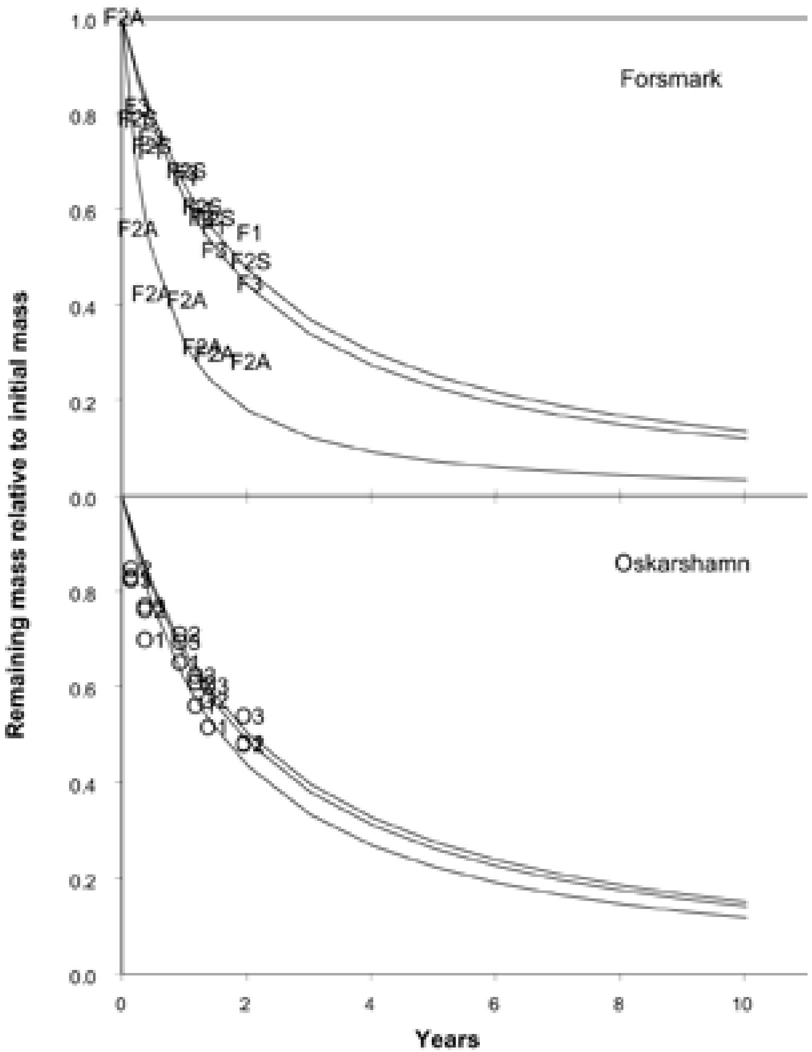

Figure 4-22. The lines represent remaining mass during modelled decomposition relative to the initial amount. Letters represent field data, where F1 and F3 are the spruce sites and F2A the alder fraction of the spruce/alder site in the Forsmark area. O1 denotes the oak site, O2, the pine site and O3 the spruce site in the Laxemar-Simpevarp area /Mjöfors et al. 2007/.

Distribution and turnover of roots

The roots of the primary producers constitute about 30 to 50 percent of their total biomass /Gower et al. 2001/. Roots serve as supporting tissue, but perhaps more important from a transport and accumulation perspective they provide the plant with all the water and nutrients that are needed for growth and survival. This means that roots constitute the most important transport route for most of the elements found in plants today, as well as elements that could potentially be found in plants. Tree roots can be distinguished by size into different categories: coarse supportive roots with low turnover rates, small diameter roots with low turnover rates that act as conduits for water and mineral nutrients and very fine mycorrhizal roots (< 1 mm in diameter) with a high degree of soil penetration and high turnover rates /Vogt and Persson 1991/. Quantifying the amount of fine roots in forest ecosystems is necessary due to their important role as carbon sinks and sources of soil organic matter /Jackson et al. 1996/. However, it may not be advisable, due to the high variability of the fine roots, to estimate the fine-root biomass as a proportion of the total root biomass or to use other structural parts of the tree for such estimations /Persson and Stadenberg 2007a, Vogt and Persson 1991/.

Biomass distribution of fine roots

/Persson and Stadenberg 2007/ investigated the distribution of root biomasses in tree and field layers at three forest localities in the Forsmark and Laxemar-Simpevarp areas, respectively (Table 6-2). They used the sequential coring technique to estimate root biomass.

The amount of live fine tree roots was high in the humus layer, especially in the uppermost part of the humus horizon. The mean fine-root biomass (< 1 mm in diameter) of tree species for the total profile was 267, 317 and 235 g m^{-2} for the Forsmark localities and 137, 371 and 50 g m^{-2} for the Laxemar-Simpevarp localities. The data on the amount of fine-root biomass and necromass in the Forsmark and Laxemar-Simpevarp areas are within the range of the data from other investigations /cf. Persson 2000/, taking into consideration the high seasonal variability of the fine roots. The concentration of fine roots in the humus layer seems to be dependent on soil water availability. Figure 4-23 shows fine root density (≤6 mm) as a function of depth for the different localities. The rather sharp decrease in Figures 4-19c and d is an effect of the high occurrence of shallow boulders. This makes the sampling difficult, but also affects the root density.

The field layer species were substantially more developed in the open forests stands, with a low stem density of the trees. Roots of tree and field layer species generally occupied different soil horizons and therefore compete with each other to a limited extent for water and nutrients. The superficial distribution pattern of field layer species compared with tree species is confirmed by data from other sites /Persson 1975, 1978, 1983/. In the total soil profile, 8–27% of the fine root biomass (< 1 mm in diameter) at the Forsmark and 1–62% at the Laxemar-Simpevarp localities consisted of fine roots of field layer species. It is important to know to what extent the distribution pattern of the tree roots is influenced by competition from the roots of the field layer species. The study suggests that tree roots are generally distributed deeper than roots from the field layer species. The highest amount of roots from the field-layer species was found on the sites with a low number of trees/ha; viz. in the “coniferous fern type forest” in the Forsmark area (780 trees ha^{-1}) and at the “herb rich oak forest” in the Laxemar-Simpevarp area (200 trees ha^{-1}). The forest trees on those sites were among the oldest (the age of the trees was 80–112 years).

Turnover of fine roots

The root function is extremely costly for the organism and is enhanced by a high carbohydrate supply /Ågren et al. 1980, Marshall and Waring 1985/. Available information in the literature suggests substantial fine root production with a seasonal pattern different from needle or leaf production /Persson 1983/. It has been demonstrated that fine roots are sensitive to drought and that their live-to-dead ratios decrease with diminishing water availability in the soil /Olsthorn 1991, Persson et al. 1995, Santantonio and Hermann 1985/. /Persson and Stadenberg 2007b/ also investigated the turnover of fine roots (< 1 mm) at the Norway spruce locality (FG1 in Table 4-19) during one

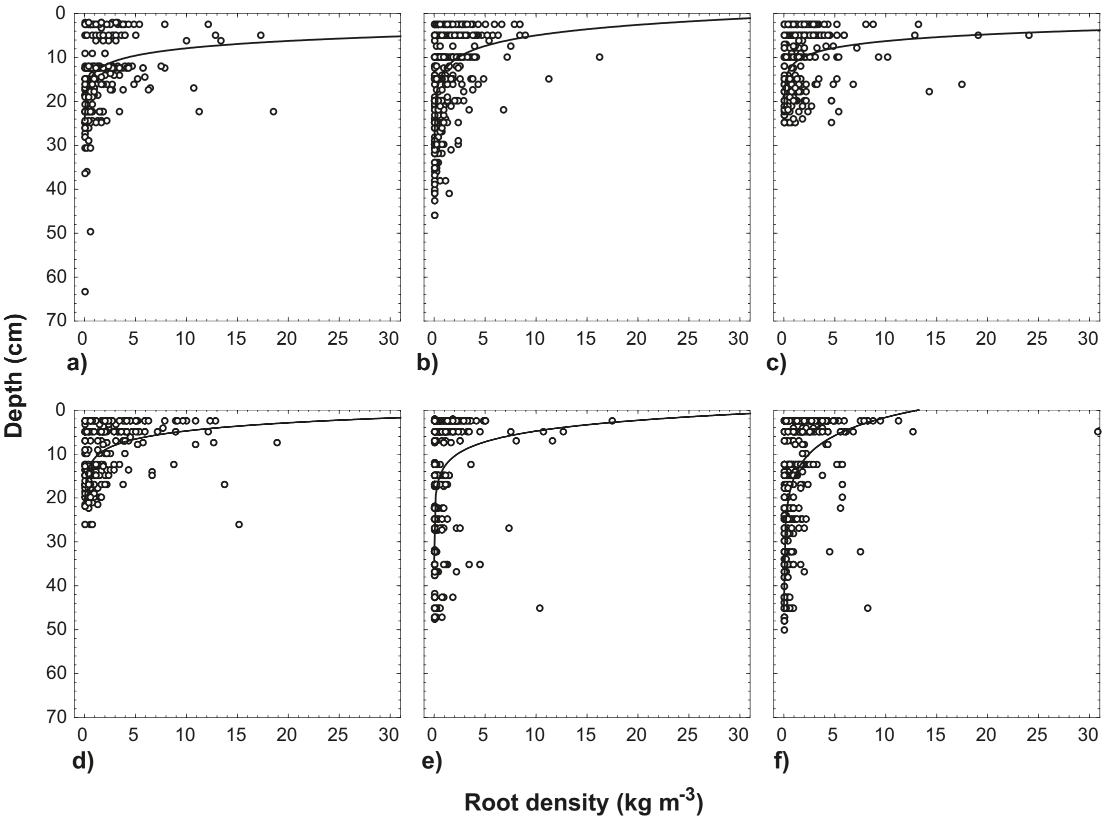

Figure 4-23. *Fine root density (≤6 mm) as a function of soil depth for the six different localities in the Forsmark (a–c) and Laxemar-Simpevarp areas (d–f) (see Table 6-2 for more details). a) Norway spruce, b) Alnus swamp forest, c) Norway spruce, d) Pedunculate oak forest, e) Norway spruce, f) Alnus shore forest. Each figure is based on 32 soil corings. A logarithmic curve is fitted to the observations. One outlier was excluded from Figure c showing a sample at 5 cm depth with a density of 51 kg m^{-3}. Data from /Persson and Stadenberg 2007a/.*

year (October 2004–October 2005) using repeated sampling of soil corings on four occasions. The turnover estimate was the accumulated results of significant differences in biomass between soil corings on four occasions, which were added in order to estimate the production of fine roots. The turnover was estimated to be 0.7 of the fine root biomass by dividing the fine root production by the average fine root biomass. The amount of fine root biomass and necromass at the Forsmark locality showed a high seasonal variability (Figure 4-24 /cf. Persson 2000/). A review of literature data from various forest stands, obtained by sequential coring, suggests annual turnover rates of 1–2 times the average fine root biomass. The mean for root diameters <1 mm was 1.0 (min=0.1, excluded from the mean, and max=1.7) and the mean for root diameters <2 mm was 1.5 (min=1.0 and max=2.4) /Persson and Stadenberg 2007b/. All those turnover rates are conservative, since turnover occurring between the sampling occasions remained undetermined.

Depth of the root zone

/Lundin et al. 2005a/ investigated the depth of the root zone, defined as the zone where fine roots (Ø < 5 mm) were found, for a number of different soil types in soil pits in the Laxemar-Simpevarp area. These vegetation types are the same as those used to describe the field and bottom layers (above). Fine root depth was estimated by /Lundin et al. 2005a/ at two localities for each of the studied soil classes except for the mire and the rockpool types. In generally, the samples from the two replicates did correspond fairly well to each other and the largest variation was found between the different vegetation types. The largest deviation from that pattern was found between the two rockpool types (HI-s). The statistics presented in Table 4-20 were obtained from all sub-samples within the vegetation type.

The depth of the root zone was also investigated in a large soil trench in the Forsmark area, where Regosols dominated /Lundin et al. 2005b/. The depth of fine roots varied between 3 and 57 cm, but most of the roots were found between 10 and 40 cm with an average of 25 cm. Coarse roots appeared to have a more shallow location with the deepest root reaching 25 cm, with an average of 10 cm.

An illustration of the variation in rooting depth is from another trench in the Forsmark area /Lundin et al. 2005b/. Depths were measured for fine and coarse roots, subdivided into two classes at a diameter of 5 mm. The soil and site type class was mainly of Regosol/Gleysol type found in upslope locations with fresh soil moisture class. Humus forms were moor or moder. The vegetation was a mixed coniferous forest dominated by Norway spruce with low herbs of bilberry type in the field layer and fresh mosses in the bottom layer. Fine roots were found in most locations and the depth varied from 3 cm to 57 cm from the mineral soil surface (Figure 4-25). At two locations there was bedrock without roots. Most of the roots reached to between 10 cm and 40 cm with an average of 25 cm. Coarse roots were observed at 19 locations with the deepest root reaching 25 cm, but on average the depth was 10 cm (Figure 4-25).

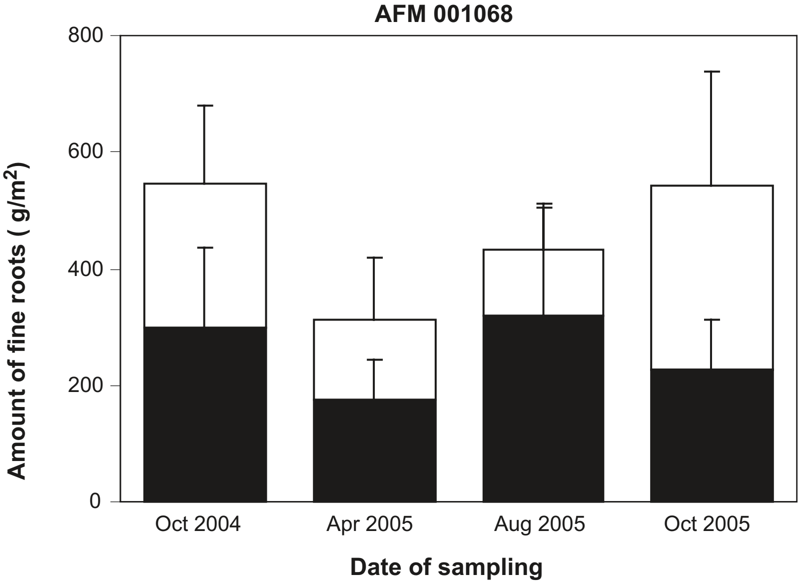

***Figure 4-24.** The amount of live (unfilled bar) and dead (black bar) fine roots (< 1 mm in diameter) on the four sampling occasions at the Norway spruce locality in the Forsmark area. Mean values ± SD. From /Persson and Stadenberg 2007b/.*

Table 4-20. Statistics describing the depth of the root zone for a number of vegetation types in the Laxemar-Simpevarp area. The class LP was not estimated in /Lundin et al. 2005a/.

Class	Code in /Lundin et al. 2005/	Mean (SD) (m)	Min–Max (m)	N
Mires	HI-w	0.34 (0.07)	0.30–0.47	7
Forested wetlands	HI-f	0.31 (0.05)	0.25–0.43	10
Herb dominated moist soils on fine texture parent material	UM/RG	0.39 (0.11)	0.20–0.60	16
Semi-natural grasslands	UM/GL	0.18 (0.12)	0.06–0.54	16
Woodland, well drained, herbs, grasses and dwarf shrubs	PZ/RG	0.26 (0.09)	0.15–0.52	16
*	HI-f*	0.22 (0.07)	0.08–0.32	16
Esker	PZ/RG-e	0.29 (0.07)	0.18–0.43	16
Rockpool	HI-s	0.20 (0.12)	0.09–0.40	14
Thin soils with lichen rich heath vegetation	LP	–	–	–
Shore line (bedrock excluded)	RG/HI	0.19 (0.13)	0.00–0.35	15
Arable land	UM/GL-a	0.15 (0.07)	0.07–0.27	16

*Reclassified from “Woodland” to “Forested wetland” by /Lundin et al. 2005a/, but is not used here for the calculation of root depth for both categories.

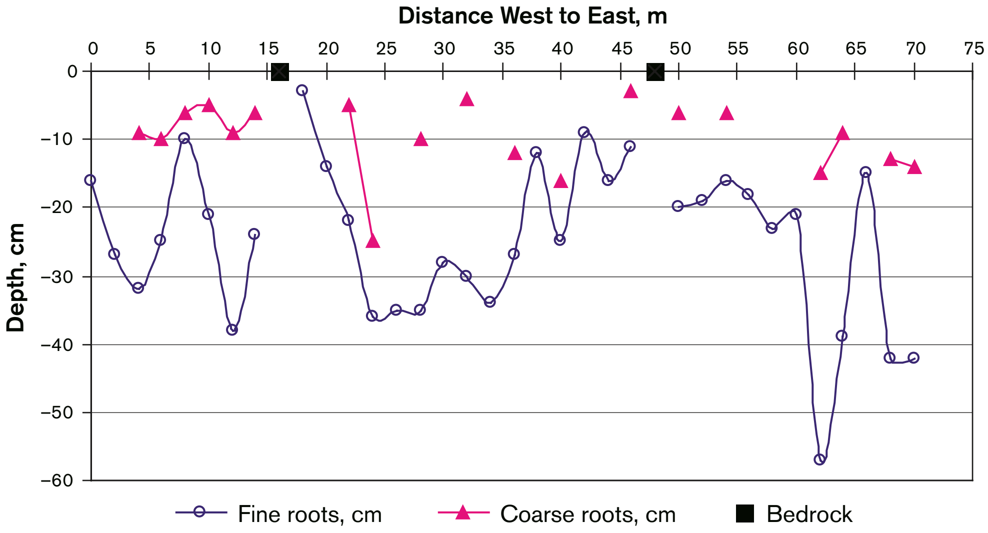

Figure 4-25. Variation in rooting depth of fine and coarse roots along a transect in the Forsmark area. The rooting depth was determined with the mineral soil surface as the upper boundary and the average humus layer thickness was 11 cm. From /Lundin et al. 2005b/.

Coarse woody debris

The coarse woody debris, consisting mainly of logs and stumps, may constitute a significant part of the carbon pool depending on the forest type and how it is managed. Generally, intensive forest management involves an active removal of dead or dying trees but also leads to even-aged tree cohorts. /Andersson 2004, 2005/ investigated the occurrence of coarse woody debris in the Forsmark and Laxemar-Simpevarp areas for a number of different forest types (Table 4-21, 4-22).

Ecosystem modelling

Dynamic modelling, by the CoupModel, was used as an approach to describe pools and fluxes of carbon for a number of ecosystems in the Forsmark and Laxemar-Simpevarp areas using site-specific input data /Gustafsson et al. 2006, Karlberg et al. 2006/. The CoupModel is a one-dimensional model for simulations of fluxes of water, heat, carbon and nitrogen in a soil-plant-atmosphere system (Figure 4-26). It has been developed to estimate interactions between climate, vegetation and conditions in the soil, and applied mainly to Nordic conditions. A detailed description of the model is given by /Jansson and Karlberg 2004/.

The carbon and nitrogen models are based on three prerequisites: 1) carbon input is governed by solar radiation, 2) carbon flows govern nitrogen flows, and 3) nitrogen in plants determines growth. Plants are represented by one pool of carbon and one of nitrogen for three compartments, stem, leafs (needles), and roots. The stem compartment represents all woody material: stems, branches and roots except fine roots. The organic material in the soil is represented in different ways depending on the purpose of the simulation. Soil organisms such as microorganisms decompose the organic matter, and their activity therefore accounts for the fluxes between different organic pools in the soil. To account for differences in substrate, the model has a minimum representation of two organic pools independent of soil horizon. One is litter, which has a high turnover rate, and the other is humus, representing a low turnover rate. Simulations including different soil temperature, soil moisture conditions and the soil water flows are based on physical equations. The most important interaction between the carbon turnover and the physical conditions is governed by the leaf area index and the ratio between actual and potential transpiration. Both will in turn influence the input of carbon to the system and both are strongly related to temperature and moisture.

Table 4-21. Biomass of standing and lying logs in gC m^{-2} in the Forsmark area. Medians and, first and third quartiles were recalculated from /Andersson 2004/, who investigated a specific area (column 3) for a number of vegetation types. Grid codes are from tree the layer classification used in /Boresjö Bronge and Wester 2003/. Field-estimated volumes were converted to dry weight using /Benediktson et al. 2005/ and carbon content was assumed to approximate the estimates from litter (0.47, according to /Mjöfors et al. 2007/).

Class	Grid code	Total area (ha)	Woody debris	Q_1	Q_3
No tree layer within forest area	1	6	38	33	49
No tree layer outside forest area	2	87	5	0	9
Old spruce	11	146	63	31	96
Old pine	13	55	52	27	59
Young pine	14	31	3	2	4
Unspecified young conifer	17	16	3	2	5
Birch	21	8	94	53	135
Young birch (thicket on clear-cut)	22	13	5	5	5
Ash	26	4	27	24	28
Mixed forest	30	14	68	48	119

Table 4-22. Biomass of standing and lying logs in gC m^{-2} in the Laxemar-Simpevarp area. Medians and first and third quartiles were recalculated from /Andersson 2005/, who investigated a specific area (column 3) for a number of vegetation types. Grid codes are from the tree layer classification used in /Boresjö Bronge and Wester 2003/. Field-estimated volumes were converted to dry weight using /Benediktson et al. 2005/ and carbon content was assumed to approximate the estimates from litter (0.47, according to /Mjöfors et al. 2007/).

Class	Grid code	Total area (ha)	Woody debris	Q_1	Q_3
No tree layer within forest area	1	57	22	14	41
No tree layer outside forest area	2	66	0	0	0
Old spruce	11	53	48	29	73
Young spruce	12	5	14	7	20
Old pine	13	185	37	21	48
Young pine	14	15	21	20	23
Unspecified young conifer	17	7	23	16	32
Birch	21	4	34	25	36
Young birch (thicket on clear-cut)	22	3	20	17	26
Birch or oak mixed with spruce	24	30	38	30	80
Oak	25	3	77	45	99
Coastal birch/oak	27	4	33	20	45
Mixed forest	30	8	53	33	67

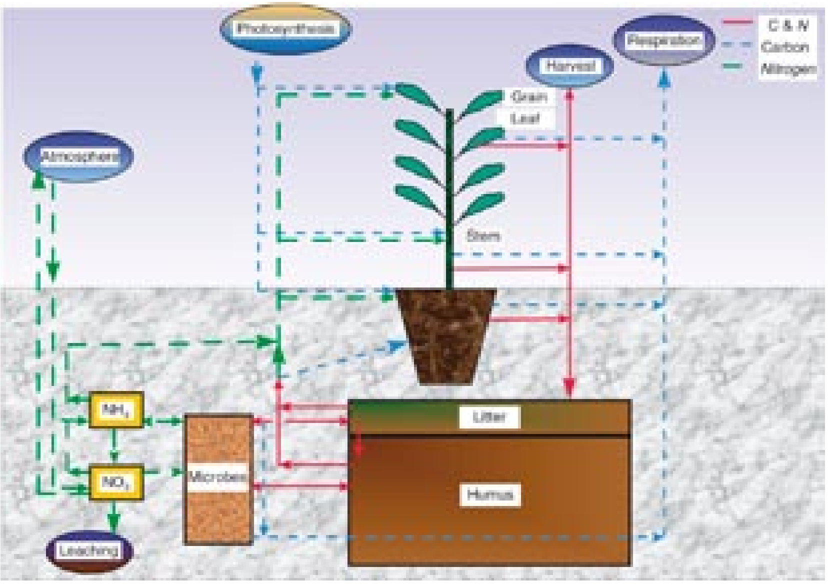

Figure 4-26. *Schematic model of carbon, nitrogen and biomass flows (in one dimension) and storages. The soil is further divided into layers and plant biomass is divided into pools of annual and perennial tissues /Gustafsson et al. 2006/.*

Results

/Gustafsson et al. 2006/ simulated carbon pools and fluxes for coniferous stands and compared averages for the ages 0–30 years, 30–100 years and 0–100 years using climate parameters describing a period of 25 years from each site. A subset of the simulated estimates is presented in Table 4-23.

/Karlberg et al. 2006/ investigated four terrestrial ecosystems in the Laxemar-Simpevarp area: a grassland on fine sand with a high soil organic matter content, an alder forest on peat, a managed spruce forest on peat and a pine forest on till. These systems were selected because they are likely to differ in terms of carbon turnover times, and also because they are commonly occurring in southern and central Sweden. Measured data on soil carbon and nitrogen content at each site were used to parameterize the initial conditions of the litter and humus pools in the site-specific simulations. Soil respiration estimates from a grassland, a spruce and pine forest stand /Tagesson 2006b/ were used to calibrate the simulations by adjusting the groundwater level, since this variable was unknown. Due to different exposure to oxygen, a change in groundwater level predominantly affects heterotrophic respiration and has a large impact on soils rich in organic matter such as those at the study-site. Continuous series from 1 January 1993 to 5 July 2005 describing precipitation, air temperature, global radiation, wind speed and relative humidity on the site were created. In order to get an estimate of the variance in the different parts of the carbon budgets, the relative variance (i.e. the standard deviation divided by the mean) calculated for four hypothetical systems was multiplied by the mean values from the site-specific simulations, see /Karlberg et al. 2006/.

Soil respiration was generally well described in the model simulations compared with the measurements by /Tagesson 2006/. None of the ecosystems are in steady state in terms of carbon storage (Figure 4-2). The annual average net ecosystem exchange for the grassland is about –600 gC m^{-2} y^{-1}, while it is close to zero in the spruce forest (–80 gC m^{-2} y^{-1}) and is positive in the alder and pine forests (230 gC m^{-2} y^{-1} and 200 gC m^{-2} y^{-1}, respectively), Figure 4-27. This means that the soil organic content decreases annually in the grassland and the spruce forest, while it increases in the alder forest and remains relatively stable in the pine forest.

Annual water flows were also estimated in the simulations (Figure 4-28). These estimates show that most of the water entering the ecosystems as precipitation leaves as subsurface drainage or surface runoff, except in the alder forest.

Table 4-23. Simulated pools and fluxes of carbon averaged for a simulated coniferous stand during the period 0–100 years /Gustafsson et al. 2006/.

Property	Forsmark area	Laxemar-Simpevarp area
Biomass (gC m^{-2})	6,743	6,826
NPP (gC m^{-2} y^{-1})	335	360
Litter production (gC m^{-2} y^{-1})	232	242
Soil respiration (gC m^{-2} y^{-1})	228	240
NEP (gC m^{-2} y^{-1})	107	120

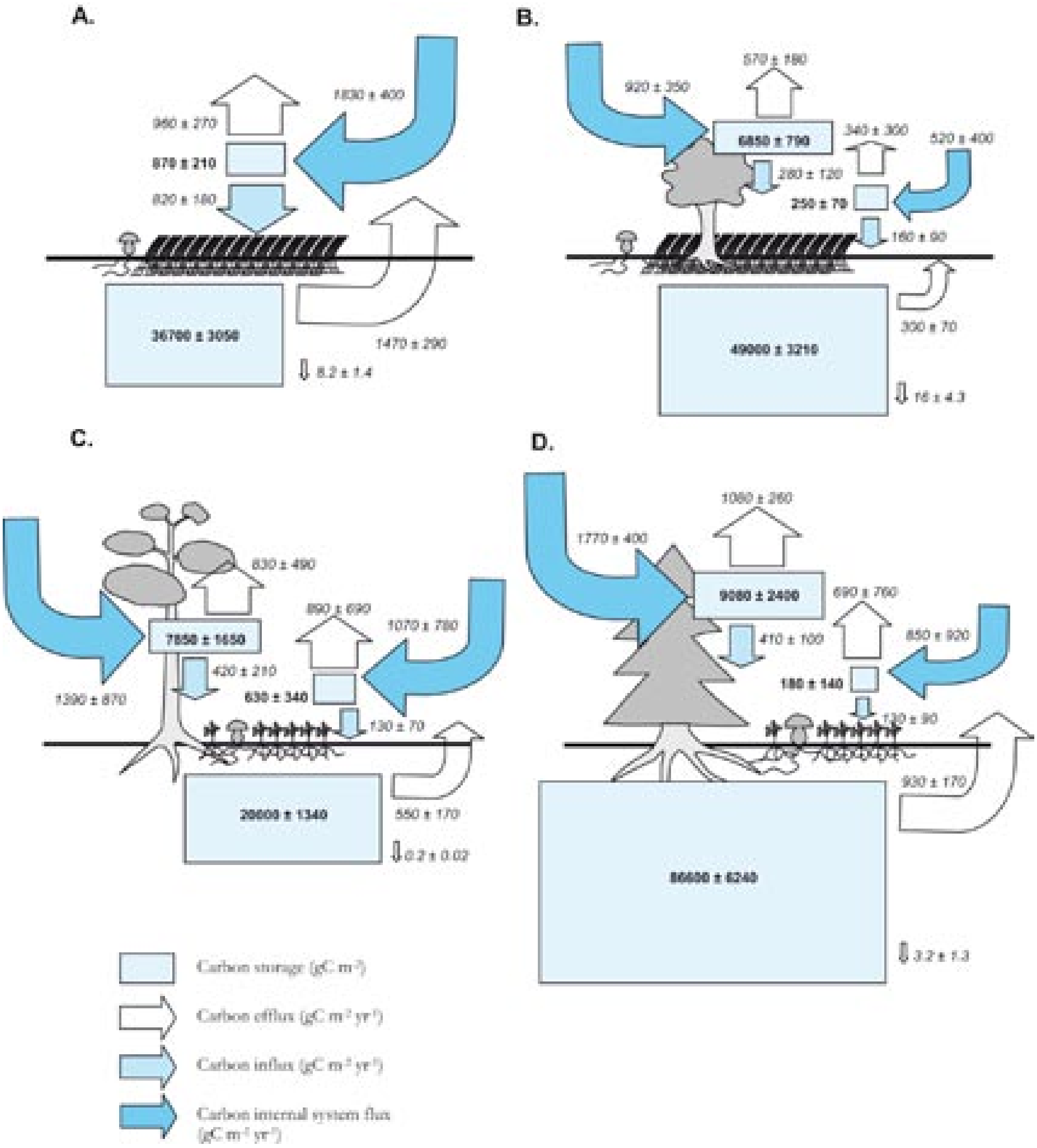

Figure 4-27. *Carbon budgets for the site-specific ecosystems located within the Laxemar-Simpevarp area. a) grassland b) alder c) pine and d) spruce managed forest. Carbon storages (gC m^{-2}) in bold and carbon fluxes (gC m^{-2} yr^{-1}) in italics, including standard deviations. /Karlberg et al. 2006/.*

Interactions between forest ecosystems and other vegetation types

Water transports elements between ecosystems, and most forests at both sites are regarded as recharge areas /e.g. Werner et al. 2007/. Some wet forests, regularly flooded forests or forested wetlands, e.g. alder swamps, may, however, act as recipients for transported elements. This is further discussed in Section 4.1. Most forests have to be regarded as a continuous source for horizontal transport of elements (weathering) to other ecosystems, such as wetlands, lakes and the sea, although this horizontal transport is usually small in comparison with internal transport within the forest ecosystem.

4.1.4 Confidence and uncertainties

Ecosystem descriptions

The vegetation has been used to categorize both the more dry and the wetland parts of the terrestrial area. Moreover, agricultural land and forest land have been used as domains for further descriptions of properties. Each of these may be broken down to further units, both because of successional trajectories within these domains (e.g. clear-cut and forest), but also because of abiotic differences affecting the vegetation type (e.g. minerogenic fen and bog). This generates variation in regard to many describing parameter, while other may be less variable e.g. soil conditions.

Generally, the descriptions are based on many sources of information, where data are compared and discussed in relation to other similar studies of which some are presented in this report. For a more comprehensive discussion and comparison with similar studies, the reader would also be recommended to read the underlying reports that are referred to. Further evaluation, comparison and discussion of data and assumptions were also done in the following chapters that extend and formalize the descriptions in terms of pools and fluxes in ecosystems.

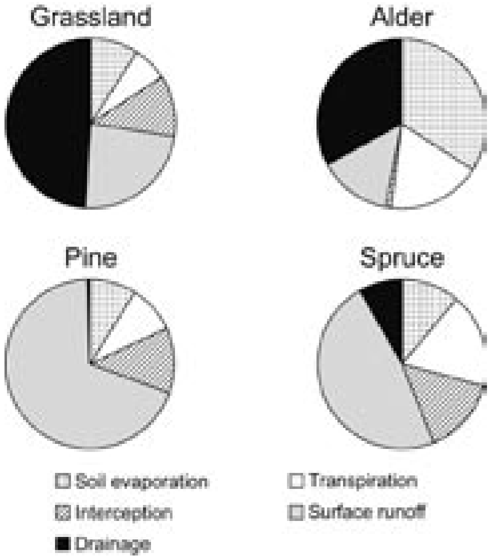

Figure 4-28. *Participation of incoming precipitation for four site-specific ecosystems located within the Laxemar-Simpevarp area. /Karlberg et al. 2006/.*

4.2 Fauna and fungi

The fauna has been investigated at the sites in a number of different investigations. Much effort has been put into characterizing and estimating densities of functional groups, i.e. large mammals, small mammals, birds, amphibians and reptiles, and thereby underpinning calculations of potential fluxes of organic matter to and between these groups (Figur 4-29). Other important functional groups are found below ground, where for example the potential transport of organic matter by soil fauna (bioturbation) might be significant. Another process of importance is mineralization, estimated as a part of soil respiration, which is an important process in evaluating the turnover of organic material in ecosystems. Fauna is treated separately from flora, mainly because larger fauna species are often more difficult to associate with specific habitats on an annual basis. However, for some species or functional groups an attempt has been made to distribute their consumption in the landscape, either by using their habitat preferences or their feeding preferences or both. From the perspective of being exposed to contaminants, i.e. radionuclides, species with more specific food requirements, associated with a certain habitat, would generally be more exposed if that habitat is contaminated than generalist species using a broader range of food sources from different habitats. In the case of other functional groups it is easier to directly link their occurrence with certain vegetation types, e.g. soil fauna and soil microbes.

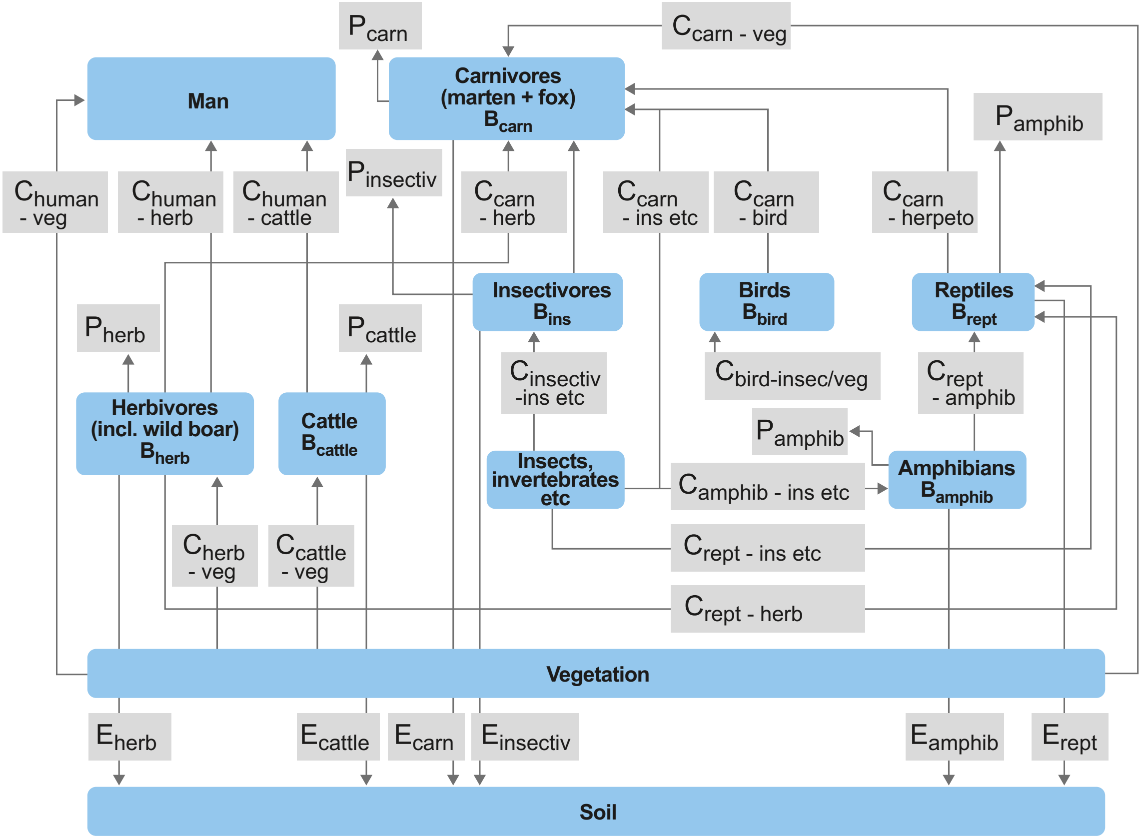

Figure 4-29. *Food web describing the pools (boxes) and fluxes (arrows) of organic matter in a terrestrial ecosystem. P is predation, C is consumption, B is biomass and E is egestion. The configuration is adapted to the information presented below in this section and the food web is therefore applicable to both sites. Estimated values for each box and arrow are found in Tables 4-31, 4-32 (mammals), 4-43, 4-44 (amphibians and reptiles) and 4-38 to 4-41 (birds) for both the Forsmark and Laxemar-Simpevarp areas, except for the box representing insects. Vegetation and soil are described in Chapters 6 to 8.*

The aims of the studies describing the fauna at the sites can be summarized as:

- Describing which species or functional groups occur in the area.
- Establishing reliable density estimates for larger animals, many of which are used as a food source for humans.
- Quantifying important pools/fluxes from the sites, which will be used for the ecosystem models.
- Establishing a baseline for an ongoing monitoring programme that can be used to relate different kind of disturbances to wildlife population changes.

In this chapter the focus is mainly on the first three points. This chapter also serves as a basis for the calculations of fluxes associated with consumers in the ecosystem modelling and mass balance models presented in Chapters 8 and 10.

4.2.1 Mammals

Description of the monitoring activities

From the site investigations, it has been possible to estimate the population densities for most of the mammal species found in the Forsmark and Laxemar-Simpevarp areas. The mammals that have been included in the surveys are listed in Table 4-24. The chosen study area was centred around the drilling activities in the Forsmark (approx. 110 km^2) and Laxemar-Simpevarp (approx. 120 km^2) areas. In addition to these areas, one reference area was selected in the same region of each site to provide further data for evaluation of the results from the specific sites. The reference area chosen for the Forsmark area was near Hållnäs, north of the Forsmark area, and the reference area chosen for the Laxemar-Simpevarp area was near Blankaholm, north of the Laxemar-Simpevarp area.

Population sizes for large mammal species were estimated using pellet counts conducted during at least two separate years, while small mammal populations where estimated using traps in the spring and autumn of 2003 and the autumn of 2004. The size of the moose population was also estimated by means of aerial surveys (Figure 4-30). Marten, lynx and fox were studied solely by snow tracking. The density estimates, generated from the surveys that are shown in Table 4-24, have been used to calculate a mean density for each species. As rodent density differs greatly between spring and autumn, the density has been estimated from the mean value for 2003. In the Laxemar-Simpevarp area, trapping for field vole and mouse (in field) was only done in the autumn, while water vole was only trapped in the spring in 2003. The densities used for these species are therefore based on a single survey /Cederlund et al. 2004/.

The bat fauna of the Forsmark and Laxemar-Simpevarp areas was surveyed using ultrasound detectors during the summer of 2004 /de Jong and Gylje 2005, Ignell 2004/. Mist nets were also used in the Forsmark area. The objective was to map the distribution of all species in the area, to identify important foraging areas and colonies and to get rough estimates of the abundance of the species.

Table 4-24. Density estimates are available for a number of mammal species from the Forsmark and Laxemar-Simpevarp areas. The density estimates are calculated from the surveys that are shown in the table /Cederlund and Truvé 2005/ and /Truvé 2007/.

Species English (Swedish)	Latin	Surveys in the Forsmark area	Surveys in Laxemar-Simpevarp area
Herbivores (Even-toed ungulates)			
Fallow deer (*Sw: Dovhjort*)	*Dama dama*	*Not found*	Pellet: 2007
Moose (*Sw: Älg*)	*Alces alces*	Pellet: 2002,2003,2007 Aerial: 2002,2004	Pellet: 2003,2007 Aerial: 2003,2007
Red deer (*Sw: Kronhjort*)	*Cervus elaphus*	*Not found*	Pellet: 2003, 2007
Roe deer (*Sw: Rådjur*)	*Capreolus capreolus*	Pellet: 2002,2003,2007	Pellet: 2003, 2007
Herbivores (Lagomorphs)			
European (common) hare (*Sw: Fälthare*)	*Lepus europaeus*	Pellet: 2002,2003,2007	Pellet: 2003, 2007
Mountain hare (*Sw: Skogshare*)	*Lepus timidus*	Pellet: 2002,2003,2007	Pellet: 2003, 2007
Carnivores			
Lynx (*Sw: Lodjur*)	*Lynx lynx*	Snow tracking:2002	Not found
Marten (*Sw: Mård*)	*Martes martes*	Snow tracking:2002,2007	Snow tracking:2003
Red fox (*Sw: Rödräv*)	*Vulpes vulpes*	*	*
Omnivores			
Wild boar (*Sw: Vildsvin*)	*Sus scrofa*	Pellet:2007	Snow tracking: 2003 Pellet: 2003, 2007
Rodents			
Bank Vole (*Sw: Skogssork/Ängssork*)	*Cletrionomus glareolus*	Trapping: spring and autumn 2003	Trapping: spring and autumn 2003
Field vole (*Sw: Åkersork*)	*Microtus agrestis*	Trapping: spring and autumn 2003	Trapping: autumn 2003
Water vole (*Sw: Vattensork*)	*Arvicola terrestris*	Trapping: spring and autumn 2003	Trapping: spring and autumn 2003
Wood mouse (*Sw: Mindre skogsmus*)	*Apodemus sylvaticus*	Trapping: spring and autumn 2003	Trapping: spring** and autumn 2003
Yellow necked mouse (*Sw: Större skogsmus*)	*Apodemus flavicollis*	Trapping: spring and autumn 2003	Trapping: spring** and autumn 2003
Insectivores			
Common shrew (*Sw: Vanlig näbbmus*)	*Sorex araneus*	Trapping: spring and autumn 2003	Trapping: spring and autumn 2003

* Density estimation not possible through snowtracking

** Spring trapping only included mice in forests, not in field.

Figure 4-30. Moose spotted during airborne inventory.

Description of the mammals in the Forsmark and Laxemar-Simpevarp areas

This section presents the mammals found at the two sites, including a short description and estimates of their population densities (Tables 4-31 and 4-32).

Moose

The aerial surveys and pellet counts performed in the winter of 2002–2007, after the hunting season, show that the mean density in the Forsmark area is 0.70 moose·km^{-2} (0.74 in Hållnäs). The low age of harvested bulls reported from the Forsmark area indicates a high hunting pressure on bulls. The average age is 2.7 years for bulls compared with 4.9 for cows. This is a consequence of a sex-biased harvest strategy. The average carcass weight is 165 kg for bulls and 154 kg for cows (2002–2006) /Cederlund and Lemel 2007a/. Fecundity (eggs/cow) among adult females is relatively high, but does not deviate from other populations in this part of the country.

In the Laxemar-Simpevarp area, the mean density between 2002 and 2007 is 0.77 moose·km^{-2} (0.41 in Blankaholm). The low carcass weight (on average 156 kg for bulls and 146 kg for cows 2002–2006) and low age (in average 2.1 years for bulls and 2.8 years for cows) reported from Oskarshamn indicate a high hunting pressure /Cederlund and Lemel 2007b/. Fecundity (eggs/cow) among adult females is moderate, but probably not lower than among other populations in this part of the country.

The moose diet consists mainly of deciduous trees and larger shrubs (approx. 45%). In the summer the moose also feeds on herbs and low shrubs to a large extent, while coniferous browse is common in the winter /Truvé and Cederlund 2005/.

Table 4-25. Density estimates from surveys of large mammals 2002–2007 in the Forsmark, Laxemar-Simpevarp and the control areas from /Truvé and Cederlund 2005/ and /Truvé 2007/.

Species	Study area	Year	Method	Mean (ind/10km^2)	SE	n
Lynx	Forsmark	2002	Snowtracking	0.2		
	Forsmark	*2007*	*Regional survey**	*0.5*		
Marten	Forsmark	2002	Snow tracking	2.4		
	Forsmark	2007	Snow tracking	14.44	14.57	
	Hållnäs	2002	Snow tracking	4.2		
	Hållnäs	2007	Snow tracking	4.69	7.28	
	Simpevarp	2003	Snow tracking	1.3		
	Blankaholm	2003	Snow tracking	0.5		
Wild boar	Forsmark	2007	Pellet	0.43	0.49	774
	Hållnäs	2007	Pellet	0.25	0.34	886
	Simpevarp	2003	Snow tracking	0.4		
	Simpevarp	2003	Pellet	2.6	1.95	887
	Simpevarp	2007	Pellet	3.36	1.62	955
	Blankaholm	2003	Snow tracking	0.5		
	Blankaholm	2003	Pellet	1.2	0.8	746
	Blankaholm	2007	Pellet	6.66	3.23	866
Red deer	Simpevarp	2003	Pellet	0.3	0.18	887
	Simpevarp	2007	Pellet	1.34	0.6	955
	Blankaholm	2003	Pellet	1.5	0.58	746
	Blankaholm	2007	Pellet	1.81	0.64	866
Fallow deer	Simpevarp	2007	Pellet	0.36	0.32	955
	Blankaholm	2003	Pellet	0.4	0.34	746
	Blankaholm	2007	Pellet	0.41	0.36	866
Roe Deer	Forsmark	2002	Pellet	59.3	11.86	656
	Forsmark	2003	Pellet	93.6	20.77	595
	Forsmark	2007	Pellet	33.3	9.34	774
	Hållnäs	2002	Pellet	37.7	9.20	549
	Hållnäs	2003	Pellet	48.0	8.24	908
	Hållnäs	2007	Pellet	24.28	6.32	886
	Simpevarp	2003	Pellet	49.0	9.30	887
	Simpevarp	2007	Pellet	37.7	8.3	955
	Blankaholm	2003	Pellet	51.6	11.00	746
	Blankaholm	2007	Pellet	34.7	8.1	866
Moose	Forsmark	2002	Aerial	2.4	0.9	
	Forsmark	2002	Pellet	8.3	2.09	656
	Forsmark	2003	Pellet	12.3	2.77	595
	Forsmark	2004	Aerial	6.5**	0.69	
	Forsmark	2007	Pellet	5.63	1.33	774
	Hållnäs	2002	Aerial	12	2.9	
	Hållnäs	2002	Pellet	6.3	1.65	549
	Hållnäs	2003	Pellet	6.7	1.62	908
	Hållnäs	2004	Aerial	6.5**	0.69	
	Hållnäs	2007	Pellet	5.53	1.08	886
	Simpevarp	2003	Aerial	7.8	1.8	
	Simpevarp	2003	Pellet	5.7	1.08	887
	Simpevarp	2007	Aerial	9.1	1.3	
	Simpevarp	2007	Pellet	8.34	1.34	955
	Blankaholm	2003	Pellet	4	1.06	746
	Blankaholm	2007	Pellet	4.2	1.03	866

Species	Study area	Year	Method	Mean (ind/10km^2)	SE	n
Hares – field	Forsmark	2002	Pellet	3.2	1.75	832
	Forsmark	2003	Pellet	3.2	1.90	883
	Forsmark	2007	Pellet	9.5	10.24	1,077
	Hållnäs	2002	Pellet	2.5	0.40	2,402
	Hållnäs	2003	Pellet	22.8	8.50	658
	Hållnäs	2007	Pellet	22.16	9.66	740
	Simpevarp	2003	Pellet	35.1	13.11	1,113
	Simpevarp	2007	Pellet	9.65	4.32	949
	Blankaholm	2003	Pellet	19.1	7.37	1,257
	Blankaholm	2007	Pellet	17.38	9.43	1,076
Hares – forest	Forsmark	2002	Pellet	4.4	3.80	1,274
	Forsmark	2003	Pellet	2.3	2.08	595
	Forsmark	2007	Pellet	24.11	20.54	774
	Hållnäs	2002	Pellet	2.3	1.97	1,048
	Hållnäs	2003	Pellet	1.5	2.23	908
	Hållnäs	2007	Pellet	3.44	2.74	886
	Simpevarp	2003	Pellet	5.2	2.83	887
	Simpevarp	2007	Pellet	10.36	5.5	955
	Blankaholm	2003	Pellet	3.2	1.86	746
	Blankaholm	2007	Pellet	2.78	3.12	866

* According to /Truvé 2007/ a regional survey performed by the County Administrative Board in Uppsala County shows that there is one family group in Forsmark and one in Hållnäs. A family group consists on average of 5.5 individuals. As the investigation area in Forsmark is 110 km^2 /Cederlund et al. 2004/ the density can be estimated as 0.5 ind per 10 km^2.

** Density estimates for 2004 are for an area including both Forsmark and Hållnäs.

Table 4-26. Density estimates from surveys of small mammals 2003–2004 in the Forsmark and Laxemar-Simpevarp areas /Cederlund and Truvé 2005/.

Species	Study area	Year	Season	Method	Mean (ind/0.01km^2)	SE	n
Mouse – forest	Forsmark	2003	spring	trapping	0.7	0.19	11
			autumn	trapping	2.8	0.38	11
		2004	–	–	–	–	–
			autumn	trapping	2.5	0.39	4
	Simpevarp	2003	spring	trapping	4.8	0.81	5
			autumn	trapping	8.9	0.74	10
		2004	–	–	–	–	–
			autumn	trapping	11.5	0.85	4
Mouse – field	Forsmark	2003	spring	trapping	0.4	0.30	4
			autumn	trapping	6.4	2.34	3
		2004	–	–	–	–	–
			autumn	trapping	0.2	0.15	4
	Simpevarp	2003	–	–	–	–	–
			autumn	trapping	6.4	2.34	3
		2004	–	–	–	–	–
			autumn	trapping	6.7	0.78	4
Bank vole – forest	Forsmark	2003	spring	trapping	2.3	0.36	11
			autumn	trapping	3.2	0.43	4
		2004	–	–	–	–	–
			autumn	trapping	7.4	0.82	4
	Simpevarp	2003	spring	trapping	4.1	0.83	5
			autumn	trapping	4.8	0.56	10
		2004	–	–	–	–	–
			autumn	trapping	3.7	0.59	4
Water vole	Forsmark	2003	spring	trapping	5.7	1.47	5
			autumn	trapping	4.8	1.35	5
		2004	spring	–	–	–	–
			autumn	trapping	7.9	1.28	4
	Simpevarp	2003	spring	trapping	5.7	1.47	5
			autumn	trapping	–	–	14
		2004	–	–	–	–	–
			autumn	trapping	4.5	0.96	4
Field vole – forest	Forsmark	2003	spring	trapping	0.1	0.03	11
			autumn	trapping	0.1	0.04	11
		2004	–	–	–	–	–
			autumn	trapping	1.5	0.13	4
	Simpevarp	2003	–	–	–	–	–
			autumn	trapping	0.3	0.06	10
		2004	–	–	–	–	–
			autumn	trapping	0.9	0.11	4
Field vole-field	Forsmark	2003	spring	trapping	0.4	0.11	4
			autumn	trapping	0.1	0.06	4
		2004	spring	–	–	–	–
			autumn	trapping	10.2	0.35	4
	Simpevarp	2003	–	–	–	–	–
			autumn	trapping	4.2	0.18	3
		2004	–	–	–	–	–
			autumn	trapping	2.3	0.17	4
Common shrew	Forsmark	2003	spring	trapping	0.2	0.09	15
			autumn	trapping	2.7	0.30	15
		2004	spring	–	–	–	–
			autumn	trapping	2.7	0.30	8
	Simpevarp	2003	spring	trapping	0.5	0.29	5
			autumn	trapping	1.5	0.26	14
		2004	–	–	–	–	–
			autumn	trapping	4.4	0.38	8

Roe deer

Roe deer is the most numerous cervid species in both Forsmark and Laxemar-Simpevarp. In the Forsmark area there was a mean density of 6.2 roe deer·km^{-2} (3.7 in Hållnäs) based on the three density estimates between 2002 and 2007. Although it is well known that roe deer density varies considerably between adjacent local areas, there is no reason to believe that the densities found in this study are exceptional /Cederlund et al. 2004/. In the Laxemar-Simpevarp area, the mean density was 4.3 deer·km^{-2} (4.3 in Blankaholm) based on estimates for 2003 and 2007.

The winter diet of a roe deer is diverse and consists of deciduous browse (37%), low shrubs (26%), lichens (Sw: *lav*) (12%) and coniferous trees (10%). The summer diet consists primarily of herbs /Truvé and Cederlund 2005/.

Fallow deer and red deer

Fallow deer and red deer have only been found in the Laxemar-Simpevarp area. The average density of red deer was estimated to be 0.08 red deer·km^{-2} based on inventories in 2003 and 2007. The red deer density was more than four times larger in 2007 (0.13 ind·km^{-2}) than in 2003 (0.03 ind·km^{-2}). The red deer population is larger in the control area Blankaholm, with an average of 0.17 deer·km^{-2}. The considerable variation between the Laxemar-Simpevarp area and Blankaholm is probably a result of a common clustering of deer. According to local managers, the populations are increasing, as is the entire population in Sweden /Cederlund et al. 2004/. Fallow deer was not found in the Laxemar-Simpevarp area by pellet counts in 2003, but was found in 2007. The density was estimated to be 0.04 fallow deer·km^{-2}.

Red deer mainly eat grasses and sedges (Sw: *halvgräs*) in the summer (62%) and even to some extent in the winter, along with low shrubs, deciduous browse and coniferous trees. Fallow deer mainly feed on grasses and sedges, foliage of broad-leaved deciduous trees and Scots pine and forbs. These four categories of food accounted for about 73% of the diet, which is similar to red deer diet /Truvé and Cederlund 2005/.

Hare

The density estimates of hare have been assigned to different habitats, where the European hare mainly feeds in open fields and the mountain hare mainly feeds in forested habitats.

In the Forsmark area, the average hare density in open field habitats was 0.53 hares·km^{-2} (European hare) based on inventories between 2002 and 2007, while it was on average 1.0 hare·km^{-2} in forests (mountain hare). In the control area of Hållnäs, the densities are reversed: higher in the fields (on average 1.6 hares·km^{-2}) than in the forests (on average 0.24 hare·km^{-2}). The high figure in the Forsmark forests is a result of a high frequency of pellets in 2007. Excluding 2007, the density would be 0.34 hare·km^{-2}. In the Laxemar-Simpevarp area, the average hare density in the open field habitat was 2.2 hares·km^{-2} based on the years 2003 and 2007, and somewhat lower, 1.8 hares·km^{-2}, in the control area of Blankaholm. The mean density was much lower in the forest, 0.8 in the Laxemar-Simpevarp area and 0.3 in Blankaholm.

Mountain hares feed mainly on grasses and herbs in summer, but in winter they browse on deciduous trees and occasionally on evergreen species. The European hare feeds to a large extent on agricultural crops and pasture vegetation all year around, and does not browse to the same extent as Mountain hare /Truvé and Cederlund 2005/.

Small mammals

The small mammals occurring in the forest are bank vole, a few field voles and mice. The mice included in the mammal survey are yellow-necked mouse and wood mouse. The common shrew inhabits both forests and open field areas. The water vole inhabits the banks of ditches, rivers, streams and lakes.

In the forests of the Forsmark area, bank vole is the most numerous rodent (275 ind·km^{-2}), followed by mice (175 ind·km^{-2}) and field voles (10 ind·km^{-2}), according to a mean value of the spring and autumn in 2003. In field areas, mice are most frequent (340 mice·km^{-2}). There are only 25 field voles per km^2. Furthermore, there are 525 water voles per km^2 in the specific habitat of water vole and 145 common shrews per km^2 in the Forsmark area. The common shrews are evenly spread over the forest and field area.

In the forests of the Laxemar-Simpevarp area, mice are the most numerous rodents (685 ind·km^{-2}) followed by bank voles (445 ind·km^{-2}), according to a mean value for the spring and autumn of 2003. There are also a small number of field voles (30 ind·km^{-2}). The abundance of mice is almost the same in the field areas (640 ind·km^{-2}) as in the forests. The field areas hold the main part of the field voles though (420 ind·km^{-2}). The density of common shrew is 100 ind·km^{-2} and the water vole has a density of 570 ind·km^{-2} /Truvé and Cederlund 2005/.

All voles are herbivorous generalists and consume green plants to a large extent during the summer. Seeds and fruits are also important food items, especially in winter. Voles collect hoards of food in the summer, which they consume during the winter. Mice are omnivores and feed on insects and larvae, but their diet consists mainly of vegetable matter. Like voles they store food when availability is high. Shrews are insectivores and feed mainly on small invertebrates such as insects, spiders and earthworms, but also on carrion /Truvé and Cederlund 2005/.

The spatial distribution of water voles

Water voles inhabit the banks of ditches, rivers, streams and lakes and the density investigations have been performed using traps along streams in the area. Their home range is estimated to be 1,904 m^2 based on allometric data in /Truvé and Cederlund 2005/. According to /BBC 2004, website/, the males have home ranges of about 130 m along the river banks, whereas females have smaller ranges of about 70 m. If an average length of 100 m is assumed for the home range, the home range will cover a 10-metre wide zone along each side of the streams. The habitat of water voles in the Forsmark area and in the Laxemar-Simpevarp area is illustrated in Figures 4-31 and 4-32.

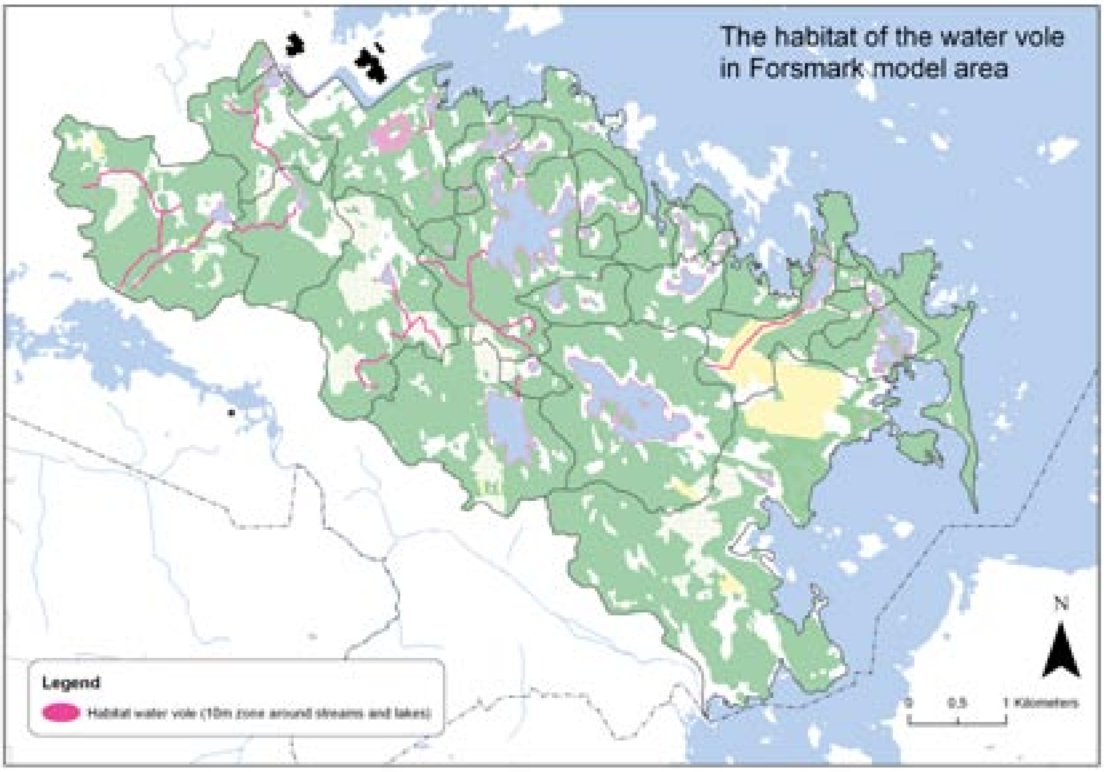

Figure 4-31. The water vole habitat in the Forsmark area, calculated and illustrated in ArcGIS using the hydrographical data in the topographic map.

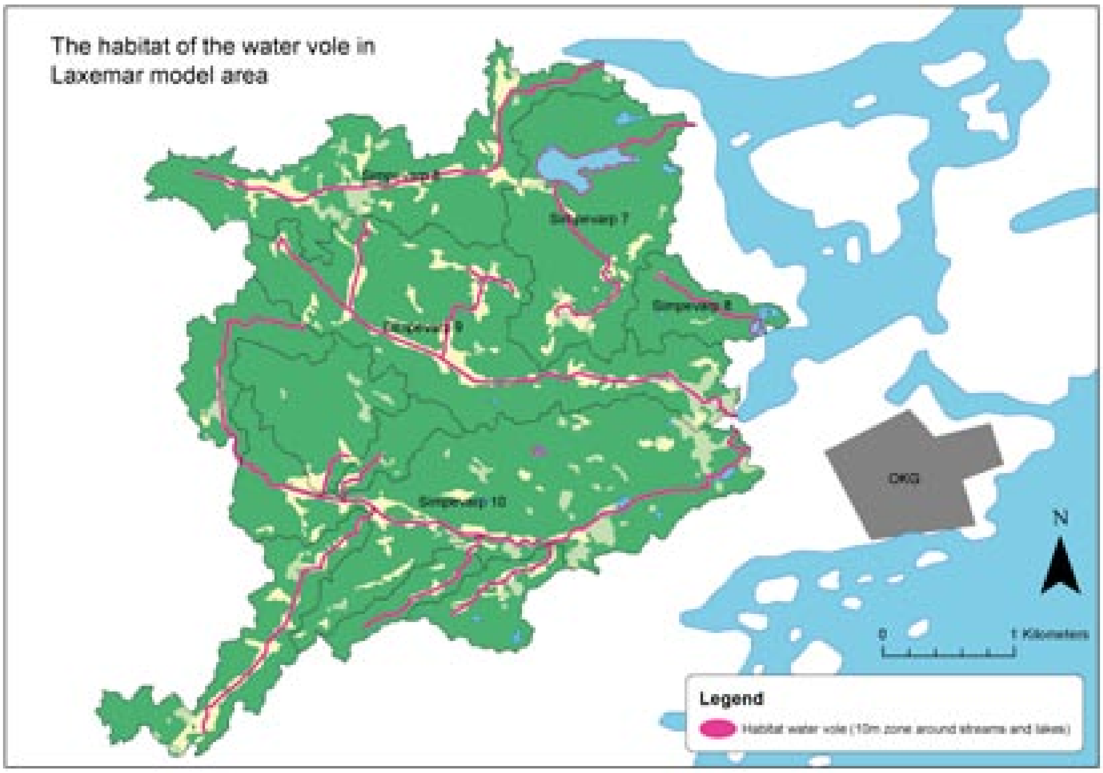

Figure 4-32. *The water vole habitat in the Laxemar-Simpevarp area, calculated and illustrated in ArcGIS using the hydrographical data in the topographic map.*

Marten

In the Forsmark area, mean marten density was estimated to be 0.84 ind·km^{-2} using inventories from 2003 and 2007, but there was a large difference between the results for the two different years. In Hållnäs, the density estimates were very similar in 2003 and 2007, with a mean of 0.44 marten·km^{-2}. Snow tracks of marten were found in both the Laxemar-Simpevarp area (0.13 marten·km^{-2}) and Blankaholm (0.05) in 2003, but not in 2007. The density estimates are relatively uncertain (large confidence intervals), but seem quite reasonable /Cederlund et al. 2004/.

According to a study in Britain, the diet of martens is diverse, but consists mainly of mammals (47%) /Truvé and Cederlund 2005/ (Table 4-27).

Red fox

The high frequency of tracks, in combination with long distances between end points and highly irregular movement patterns, made it too difficult and time consuming to estimate the red fox density. There is therefore no site-specific density data for fox /Cederlund et al. 2004/. A generic density figure has been found on /Svenska Jägareförbundet 2004, website/. According to this source, the density of red foxes in Sweden varies between 0.2 and 0.8 per km^2. The highest density is found in agricultural areas in the southern parts of Sweden. As forests dominate both in the Forsmark and the Laxemar-Simpevarp area, a density of 0.2 has been applied to the areas.

Like the marten, the red fox has a mixed diet. Red foxes feed mainly on rodents (minimum 32%), hares (minimum 35%) and birds (minimum 18%) during the summer, but several other animals as well as plants are consumed /Truvé and Cederlund 2005/ (Table 4-28).

Table 4-27. Diet of martens in Britain from /Truvé and Cederlund 2005/.

Food item	%
Mammals	47
Birds and eggs	15
Invertebrates and other	24
Fruits and vegetables	10
Hepetofauna (amphibians and reptiles)	4
Sum	100

Table 4-28. Red fox summer diet in Finland /Truvé and Cederlund 2005/.

Food item	Frequency of occurrence (min. %)
Herbivores (rodents and hares)	70
Birds	18
Insects	5
Other plants	7
Sum	100

Lynx

Tracks were found in the Forsmark area in 2002 (0.02 ind·km^{-2}). In 2007 a few tracks crossed the line but they were hard to follow since they passed lakes and wetlands with thin ice. Consequently, it was not possible to estimate population density. However, the results of surveys conducted by the Uppsala County Administrative Board show that there is one family group in the Forsmark area and one in Hållnäs. A family consists on average of 5.5 individuals. As the Forsmark area is 110 km^2, this gives a density of 0.05 ind·km^{-2} (Truvé, pers. comm.). The mean density in the Forsmark area is therefore 0.035 lynx·km^{-2}. No tracks of lynx have been found in the Laxemar-Simpevarp area. However, since lynx move over large areas, it is reasonable to believe that they occasionally pass through the Laxemar-Simpevarp area.

Lynx mainly feed on hares and deer species, but also on rodents, grouse and fox /Truvé and Cederlund 2005/.

Wild boar

According to local game managers, the wild boar population is fairly new in the Forsmark and Laxemar-Simpevarp areas and they are still at a low density. However, a rapid increase is expected in both areas /Cederlund et al. 2004/. The population growth of wild boar is 13% in central Sweden, on a yearly basis /Lemel 1999/. In the Forsmark area, only occasional tracks and no pellets were found in 2003, and therefore it was impossible to make any density estimate. In 2007 the pellet counts showed a density of 0.04 boar·km^{-2}, which was twice as high as in Hållnäs (0.02 boar·km^{-2}). The mean density in the Laxemar-Simpevarp area was estimated to be 0.21 boar·km^{-2} and in Blankaholm 0.36 boar·km^{-2}. The boar density according to pellet counts was approx. 30% higher in 2007 than in 2003.

There are large differences in rates of change between the results from snow tracking and faecal counts of wild boar, but neither of the methods has been thoroughly evaluated, which makes it difficult to assign either of the methods any real credibility /Truvé 2007/.

A wild boar is 85% herbivorous (vegetation and mushrooms) and 15% carnivorous /Lemel 1999/.

Domestic animals

The stock of domestic animals in Forsmark parish and the Laxemar-Simpevarp area has been obtained from SCB and was compiled in /Miliander et al. 2004ab/ together with the carcass weights of the domestic animals. As there is only one farm in the Forsmark area, no agricultural statistics have been accessible for reasons of secrecy. Instead, the data for Forsmark parish has been applied to the Forsmark area. The Forsmark area and the Laxemar-Simpevarp area are defined in /Miliander et al. 2004ab/.

The density was calculated as the number of animals divided by the area for fodder production and grazing (see Section 4.1.2). The cattle density is almost equal in the Forsmark and Laxemar-Simpevarp areas (66 and 62 cows per km^2, respectively). There are 31 sheep per km^2 in the Forsmark area, but only 7 ind·km^{-2} in the Laxemar-Simpevarp area. There are only pig farms in the Laxemar-Simpevarp area (36 ind·km^{-2}).

According to /Arnesson 2001/, 1.8–3.0 hectares is required to produce the fodder for one cow. That corresponds to a density of approximately 42 cows per km^2. According to statistics from SCB, the cow density in the Forsmark and Laxemar-Simpevarp areas is higher, which can be explained by the fact that only 63% of the cow fodder is self-produced by the farms and the rest is purchased /Swedish Dairy Association 2007/.

Bat

Seven species of bat were found in the Forsmark area by /de Jong and Gylje 2005/ (Table 4-29). Two additional species have been found in earlier surveys. Three of these nine species are red-listed. The most interesting observation is the colony of Nathusius pipistrelle found at Kallerö in the southernmost part of the study area. Most of the Forsmark area contains few species and low abundance. In these parts the Northern bat dominates. However in some other parts, especially Forsmarks bruk, Habbalsbo, Johannisfors, Kallerö and Storskäret, species richness and abundance is relatively high.

In the Laxemar-Simpevarp area, the inventory resulted in nine species being identified within the area of investigation /Ignell 2004/ (Table 4-29). Two different environments have been identified as especially valuable to bats within the area of investigation. These two areas are the near-mainland farms and wind-shielded sites in the archipelago. Two red-listed species were found in the investigation area. Two colonies were discovered, one colony of *Nathusius pipistrelle* in the house at Lilla Simpevarp and one of brown long-eared bat in one of the summerhouses at Mederhult.

In total, ten species were found in both areas, which is half of the number of species found in Sweden. Of the 18 species of bats found in the country, five are rare and only recorded in a few cases /Ahlén 2004/. /Ignell 2004/ did not consider the species richness in the Laxemar-Simpevarp area to be high, as 11 to 13 species can be found in the most species-rich areas in Sweden /Ahlén 2004/. /de Jong and Gylje 2005/, on the other hand, considered the number of bats in the Forsmark area to be high. The bat fauna is almost identical in the two areas, aside from the parti-coloured bat that was found only in the Laxemar-Simpevarp area.

Table 4-29. Species of bats found in the Forsmark /de Jong and Gylje 2005/ and Laxemar-Simpevarp areas /Ignell 2004/.

Species Latin name	English name	Swedish name	Forsmark area	Laxemar-Simpevarp area
Myotis daubentonii	Daubenton's bat	Vattenfladdermus	Yes	Yes
Myotis brandtii	Brandt's bat	Brandts fladdermus	Yes	Yes
Myotis mystacinus[1]	Whiskered bat	Mustasch- fladdermus	Yes	Cannot be excluded[3]
Myotis nattereri[1]	Natterer's bat	Fransfladdermus	Yes, but not in this survey	Yes
Vespertilio murinus	Parti-coloured bat	Gråskimlig fladdermus	No	Yes
Pipistrellus nathusii[2]	Nathusius pipistrelle	Trollfladdermus	Yes	Yes
Pipistrellus pygmaeus	Common pipistrelle	Dvärgfladdermus	Yes	Yes
Eptesicus nilssonii	Northern bat	Nordisk fladdermus	Yes	Yes
Nyctalus noctula	Noctule	Stor fladdermus	Yes	Yes
Plecotus auritus	Brown long-eared bat	Långörad fladdermus	Yes, but not in this survey	Yes

[1] Redlisted, classified as vulnerable (VU)
[2] Redlisted, classified as near threatened (NT)
[3] Whiskered bat and Brandt's bat cannot be distinguished in field without being caught.

Food web properties

From knowledge of what species are present, what they eat and how abundant they are in the area, it is possible to construct a food web and calculate the fluxes of energy or carbon within this food web. The methodology and the results used to describe pools and fluxes of the mammals in the food web are presented below.

Calculation of properties

Free-living mammals

The biomass has been calculated based on the density estimates that are presented in the previous section. These densities were estimated after the hunting season for moose, roe deer and hare and were therefore adjusted by increasing the estimated density with a value corresponding to some of the loss (see below) from hunting in the area, using local hunting statistics presented in /Miliander et al. 2004ab/. This was done in order to provide the ecosystem model with a more appropriate annual consumption estimate for these animals. 40% of the harvested moose are calves and 60% are adults according to /Miliander et al. 2004ab/. A calf consumes vegetation for a period of almost three months (Aug–Oct) before the hunting season, while the harvested adults consume for ten months (Jan–Oct). On a yearly basis, 60% of the harvested moose live and consume throughout the year, as $0.6 \cdot (10/12) + 0.4 \cdot (3/12) \approx 0.6$. 60% of the loss from hunting has therefore been added to the estimated density figures. The same procedure has been applied to roe deer and hare.

In calculating the standing stock of carbon for each species, the population density was multiplied by the body mass (g) given in /Truvé and Cederlund 2005/ and the carbon content. According to site-specific analysis of chemical composition in deposits and biota in the Forsmark and Laxemar-Simpevarp areas /Hannu and Karlsson 2006, Engdahl et al. 2006/, mammal muscles contain on average 11.7% carbon based on the fresh weight (44.9% based on the dry weight). This value is lower than the factors given in both /Emsley 1998/ and /Sterner and Elser 2002/, who state that the carbon content of mammals is 22.9% based on the fresh weight and 57% based on the dry weight. Despite the divergence from other references, the site-specific values are used.

The fluxes of matter – i.e. consumption, production, respiration and egestion – for each species has been calculated based on its field metabolic rate (FMR). FMR is the total rate of energy conversion for a wild animal, including the basal metabolic rate (BMR), thermoregulation, locomotion, feeding, predator avoidance, reproduction, growth and other energy consuming activities. When used to analyze energy budgets, FMR is the same as the assimilated energy (A) and is often broken down into rate of production (growth and reproduction) and respiration (metabolic heat loss), expressed as: FMR=A=P+R /Brown et al. 2004/. Like BMR, FMR is strongly correlated with body mass in eutherian mammals (mammals with a placenta).

The total energy budget for an organism is often expressed as /Baird and Ulanowicz 1989/:

$C = P + R + E$

C = consumption or total intake

P = production

R = respiration

E = egestion (faecal matter)

The calculations of carbon flows have been performed in the following order:

1. The field metabolic rate (FMR) in kJ day^{-1} was calculated for different species using the formula $FMR=ax^b$, where x is body mass, a and b are known parameters for carnivores, herbivores, omnivores, rodentia in general and mesic rodents (rodents in moderately moist environment, assumingly water vole) /Nagy et al. 1999/.
2. Production (P) and respiration (R) were estimated using the formula FMR = P+R. Production and respiration were distinguished by using an estimate of average production efficiency (P/A in %) for small mammals, other mammals and insectivores /Humphreys 1979/. The P/A-factor for the category “small mammals” was used for rodents, while the factor for the category “other mammals” was used for herbivores and carnivores, and the factor for the insectivores was used for common shrew.
3. Consumption (C) in kJ day^{-1} was calculated in two steps:

First, the FMR (kJ day^{-1}) was divided by a conversion factor for the metabolizable energy available from a gram of dry matter (DM) in the animal diet, giving consumption (C) in g DM/day. The conversion factors for different mammal groups – mammalian carnivores, herbivores, omnivores and insectivores – are found in /Nagy et al. 1999/

Second, C (in g/day) was multiplied by the total energy content (kJ g dry matter) of different diets /Golley 1961/, giving consumption (C) in kJ day^{-1}.

4. Egestion (E) was calculated using the formula C=P+R+E.
5. The figures were finally converted to carbon content by equating 1 g carbon to 10.94 kcal= 45.8 kJ /Salonen et al. 1976, Humphreys 1979/.

Domestic mammals

According to the agricultural statistics there is one agricultural enterprise (farm) in use within the Forsmark area. It is known that this farm has beef cattle. For reasons of secrecy, no data are available concerning the production at this farm. When calculating the production of animal products in the Forsmark area, the densities of domestic animals in Forsmark parish have been applied to the Forsmark area. Agricultural statistics for the Laxemar-Simpevarp area have been obtained from Statistics Sweden.

The carbon pool of domestic animals was estimated based on the density figures from /Miliander et al. 2004ab/. The carcass weights are given in /Miliander et al. 2004ab/. The conversion factors between live weight and carcass weight are shown in Table 4-30. The carbon content in domestic animals is assumed to be 11.7% of the fresh weight as for the wild mammals.

The carbon flows for domestic animals were not estimated using the field metabolic rate, as that method is based on free-living animals. Dairy cows and porkers are intensively managed and are very productive with regard to meat production. Their consumption is therefore not comparable to that of wild herbivores. Consumption has instead been estimated based on literature data. If the previous approach using the FMR equations had been used instead, consumption for cattle would be half as large, which means smaller figures for production, respiration and egestion.

According to /Swedish Dairy Association 2007/, a dairy cow consumes 18 kg day^{-1}, of which 9.6 kg is coarse fodder (grass and ensilage) and 8.4 kg is concentrated fodder. A sheep consumes approximately 584 kg dw y^{-1} (1.6 kg dw day^{-1}) of crop silage and grass silage /Löfquist 2005/. The pig diet consists mainly of seeds. At a weight of 105 kg, a sow consumes approximately 2.9 kg dw day^{-1} (1,060 kg dw y^{-1}) /Siljander-Rasi and Partanen 2007/.

The carbon content of the domestic animal diet is assumed to be 0.46 gC per g dw, the same as for the green field layer in /Fridriksson and Öhr 2003/. Production (P) has been assumed to be equal to the live weight of the slaughtered animals. Calculation of faeces production (egestion, E) for the domestic animals, the proportion between E and R in the FMR-calculations for free-living animals was used, giving an E of 42.7% of the energy input (consumption, C). The respiration (R) was calculated by using the formula C=P+R+E. The calculations of cattle milk production are presented in Section 4.1.2.

Results

Figures describing density, biomass, production, consumption, egestion and respiration per unit area for the two sites are presented in Tables 4-31 and 4-32.

Table 4-30. Conversion factors for live weight to carcass weight for cattle, pig and lamb.

Figure	Value	Source
Live weight of a cow	The carcass weight is 55% of the live weight	Assumed to be the same as for the game meat, given by (Cederlund 2004, pers. comm.).
Live weight of a pig	The carcass weight is 75% of the live weight	A carcass weight of 85 kg for a pig is equivalent to a live weight of 114 kg according to /Persson and Mattsson 2002/
Live weight of a lamb	The carcass weight is 39% of the live weight	A carcass weight of 17.5 kg for a lamb is equivalent to a live weight of 45 kg according to /Edberg (ed.) 2006/

Table 4-31. General figures per unit area describing densities, biomass, production, consumption, egestion and respiration for the mammals in the Forsmark area.

Mammal species		Habitat	Density	Biomass (standing stock)		Production	Consumption	Egestion (Faeces)	Respiration
			Number per km^2	Body mass g·ind^{-1}	Bio mass mgC m^{-2}	mgC m^{-2} y^{-1}	mgC m^{-2} y^{-1}	mgC m^{-2} y^{-1}	mgC m^{-2} y^{-1}
Herbivores (Even-toed ungulates)	Moose	Forest+Field	1.0	300,000	36	7.0	397	174	216
	Roe deer	Forest+Field	7.3	25,000	21	10	574	251	312
Herbivores (Lagomorphs)	European hare	Field	0.7	3,800	0.3	0.3	16	7	9
	Mountain hare	Forest	1.1	3,000	0.4	0.4	22	9.6	12
Herbivores (domestic)	Cattle	Field area (grain area excluded)	66	527,000/ 200,000	3,443	1,160	199,857	85,339	106,016
	Cattle (milk prod.)					7,343			
	Sheep	Field area (grain area excluded)	31	66,000/ 46,000	203	79	8,480	3,621	4,780
Carnivores	Marten	Forest	0.84	1,250	0.12	0.20	8.3	1.83	6.2
	Red fox	Forest+Field	0.20	6,000	0.14	0.18	7.4	1.7	5.6
	Lynx	Forest	0.035	30,000	0.12	0.12	5.11	1.14	3.85
Omnivorous	Wild boar	Forest+Field	0.043	60,000	0.3	0.11	5	1.0	3.5
Rodents	Bank Vole	Forest	275	23	0.7	1.7	199	87	110
	Field vole	Field	25	30	0.1	0.2	22	10	12
	Field vole	Forest	10	30	0.04	0.07	9	3.8	5
	Mouse	Field	340	23	0.9	2.1	246	108	136
	Mouse	Forest	175	23	0.5	1.1	127	56	70
	Water vole	around water[1]	525	74	4.5	9.2	1,090	478	603
Insectivores	Common shrew	Forest+Field	145	8.5	0.14	0.25	35	5.9	29

Table 4-32. General figures per unit area describing densities, biomass, production, consumption, egestion and respiration for the mammals in the Laxemar-Simpevarp area.

Mammal species		Habitat	Density	Biomass (standing stock)		Production	Consumption	Egestion (Faeces)	Respiration
			Number per km^2	Body mass $g \cdot ind^{-1}$	Biomass mgC m^{-2}	mgC m^{-2} y^{-1}	mgC m^{-2} y^{-1}	mgC m^{-2} y^{-1}	mgC m^{-2} y^{-1}
Herbivores-(Even-toed ungulates)	Fallow deer	Forest+Field	0.04	70,000	0.3	0.1	5	2.4	3.0
	Moose	Forest+Field	1.07	300,000	37.5	7.3	415	182	226
	Red deer	Forest+Field	0.08	170,000	1.6	0.4	22	10	12
	Roe deer	Forest+Field	5.6	25,000	16.5	7.8	439	193	239
Herbivores (Lagomorphs)	European hare	Field	2.4	3,800	1.1	1.0	56	24	30
	Mountain hare	Forest	0.84	3,000	0.3	0.3	17	7	9
Herbivores-(Domestic)	Cattle	Field area (grain area excluded)	62	527,000/ 200,000	3,125	1,084	186,811	80,142	99,558
	Cattle (milk prod.)					6,027			
	Sheep	Field area (grain area excluded)	7	66,000/ 46,000	43.4	17	1,815	778	1,019
	Pigs	Field area (grain area excluded)	36	114,000	483	827	17,713	7,599	9,287
Carnivores	Marten	Forest	0.13	1,250	0.02	0.03	1.3	0.28	1.0
	Red fox	Forest+Field	0.20	6,000	0.14	0.18	7.4	1.7	5.6
Omnivorous	Wild boar	Forest+Field	0.21	60,000	1.5	0.56	22	5	17
Rodents	Field vole	Field	420	30	1.5	3.1	368	161	203
	Mouse	Field	640	23	1.7	3.9	464	203	257
	Field vole	Forest	30	30	0.11	0.22	26	11.5	15
	Mouse	Forest	685	23	1.8	4.2	496	218	275
	Bank Vole	Forest	445	23	1.2	2.7	323	141	178
	Water vole	around water[1]	570	74	4.9	10	1,183	518	655
Insectivores	Common shrew	Forest+Field	100	8.5	0.10	0.17	24	4.1	20

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[1] A habitat zone of 10 m along each side of streams and lakes has been assumed.

Conclusions and comparison between the two sites

Density estimates

Comparing the density of species in 2007 relative to 2002/2003 reveals a number of changes within populations during this time. The underlying causes of such changes are often unknown, and may stem from several processes of a more or less complicated nature. Surveys conducted on two subsequent occasions are not sufficient to draw conclusions concerning long-term population trends /Truvé 2007/. Such conclusions require longer data series. For instance, a difference in population size between two subsequent surveys could either be the result of a long term trend, or the result of a fluctuating population size, with a normally distributed annual variation.

In the Forsmark area, moose and roe deer populations have declined during the period of investigation (2002–2007), which seems to be a general trend in the whole county. The standing stock of moose is comparable in the Forsmark area and the Laxemar-Simpevarp area, while the roe deer biomass is somewhat larger in the Forsmark area. According to the National Association of Huntsmen (*Sw: Svenska Jägareförbundet*) the normal density of moose is 1–1.5 moose·km^{-2} /Svenska Jägareförbundet 2007, website/. The figures from the Forsmark and Laxemar-Simpevarp areas are within this interval and can therefore be regarded as average figures. The density of roe deer can be up to 40 roe deer per km^2 in favourable areas in the south and middle of Sweden /Svenska Jägareförbundet 2007, website/. The much lower estimates from the site is by no means exceptional according to Cederlund (pers. comm.).

There is a recently established lynx population in the Forsmark area and a larger population of marten (six times the biomass in the Laxemar-Simpevarp area). This result corresponds to the large-scale species distribution in Sweden. Red deer, fallow deer and wild boar have recently become established in Laxemar-Simpevarp. These densities are increasing.

According to a study in northern parts of Sweden, the density of mountain hare can be 2–2.5 hares per km^2 in the forests of Norrland /Svenska Jägareförbundet 2007, website/. Compared to that figure the density in the Forsmark and Laxemar-Simpevarp areas is half as large. Hare populations have high interannual variation and the results are within the limits of what can be expected.

Wild boars do exist in both the Forsmark and Laxemar-Simpevarp areas. Their occurrence is though not as high as it can be in other parts of Sweden, with a maximum density of 1 boar per km^2 /Svenska Jägareförbundet 2007, website/. The wild boar populations have increased at an amazing rate, a phenomenon the area shares with many other parts of the country.

The standing stock of small mammals is notably larger in the Laxemar-Simpevarp area than in the Forsmark area (all species together). In the field it is 3 times larger and in forest 2.5 times larger. This is probably due to habitats of better quality (higher abundance of food resources and/or better nutritional quality of food items). Rodents show large regional variations.

Domestic animals have a significantly higher biomass per unit area than free-living animals. Their spatial distribution is, however, very limited and concentrated to agricultural areas (area for grain production excluded), which are sparse in both the Forsmark and Laxemar-Simpevarp areas.

Spatial distribution

An effort has been made to distribute the two predominant herbivores, moose and roe deer, among habitats in the landscape.

/Nikula et al. 2004/ studied moose habitat use in central Finland 1993–1996 by comparing the habitat composition of 54 home ranges with the overall landscape, and by comparing the habitat composition of the home ranges with the composition around moose locations within their home range. According to the study, the younger successional stages, especially pine-dominated habitats, seem to determine habitat selection by moose at the home range level, i.e. the amount of young successional stages has to be high enough to provide a suitable environment for moose. Only when the proportion of younger successional stages is high enough at the home range level is the mixture of other habitat types important for selection of home range habitat. Moose home ranges are located in areas with significantly fewer human settlements and, in the winter, significantly fewer agricultural fields than the average landscape. /Fisher and Wilkinson 2005/ have studied moose abundance in four successional stages of the boreal forests of North America. Moose were most abundant in the two youngest stages: the initiation stage (0–10 years) and the establishment stage (11–25 years). Moose abundance decreases at the aggradation stage (26–75 years) (higher abundance in clear-cuts than in burns), while moose tend to avoid old/mature stands. Accordingly, moose seem to prefer young forests (mainly pine forests). Within the home range though, different habitats are used. They tend to avoid agricultural fields, especially in winter, and also to avoid old/mature forests (>76 years). Even so, it seems like the moose is a habitat generalist, occurring more or less frequently in different habitats. Moose food selection also indicates that the moose is a habitat generalist, as its diet is diverse (see above). Accordingly, the moose has not been assigned specific habitats in our calculations.

/Hansson 2002/ has studied foraging and movement within two different habitats: isolated deciduous woods and extensive conifer forest. Roe deer trails were more common inside the deciduous woodlands, both in centres and at edges, than in neighbouring coniferous forest. When comparing abundance in coniferous forest adjoining deciduous woodlands with an extensive coniferous forest, roe deer did not show any clear differences. Roe deer seem to prefer deciduous woods, but they do inhabit coniferous forests and field areas. Food selection confirms this statement as the winter diet is diverse and the summer diet consists primarily of herbs (see above). Accordingly, the roe deer has not been assigned specific habitats in our calculations.

Consumption

The resulting consumption figures in Table 4-31 and 4-32 shows that the largest herbivores have the largest intake of carbon per area unit. The domestic herbivores do browse on a very concentrated area though, while the moose and roe deer use forest areas as well as field areas for consumption. The mammal species that consume most are the mammal spieces that are used as food sources for humans. Hence, there is a potential indirect pathway for radionuclides from vegetation to humans in the event of a radionucklide release from the planned deep repository.

4.2.2 Birds

Species

Monitoring of birds in the Forsmark and Laxemar-Simpevarp areas has been performed annually between 2002 and 2006, where one aim has been to investigate whether changes in numbers of breeding birds can be related to disturbances from the site investigations /Green 2007/. Between 2002 and 2004, a combination of line transects and point counts were used to survey the breeding birds in the area /Green 2005a/. The most common bird species in the Forsmark and Laxemar-Simpevarp areas according to the breeding bird counts between 2002 and 2004 are listed in Tables 4-33 and 4-34. In 2005 to 2008 the monitoring was focused on selected listed species and the investigation was performed by surveys of known territories and/or suitable habitats /e.g. Green 2006b, 2007/.

Table 4-33. The fifteen most common nesting species in the Forsmark area, presented as the total number of birds registered and the number of birds per km in transect surveys /Green 2005a/.

Species English (Swedish)	Latin	Total number (2004)	Abundance (n/km) 2004	Abundance (n/km) 2003	Abundance (n/km) 2002
Willow Warbler (Lövsångare)	*Phylloscopus trochilus*	460	10.22	8.62	11.31
Chaffinch (Bofink)	*Fringilla coelebs*	444	9.87	13.27	11.36
Robin (Rödhake)	*Erithacus rubecula*	206	4.58	4.04	3.54
Common gull (Fiskmås)	*Larus canus*	198	4.40	4.09	1.36
Greylag goose (Grågås)	*Anser anser*	116	2.58	2.95	2.65
Song Thrush (Taltrast)	*Turdus philomelos*	98	2.18	3.83	1.81
Blackbird (Koltrast)	*Turdus merula*	87	1.93	2.26	2.46
Siskin (Grönsiska)	*Carduelis spinus*	74	1.64	1.81	3.57
Wood Pigeon (Ringduva)	*Columba palumbus*	67	1.49	1.05	1.01
Great Tit (Talgoxe)	*Parus major*	58	1.29	1.33	1.27
Goldcrest (Kungsfågel)	*Regulus regulus*	56	1.24	2.09	0.54
Tree pipit (Trädpiplärka)	*Anthus trivialis*	37	0.82	0.56	0.87
Yellowhammer (Gulsparv)	*Emberiza citrinella*	37	0.82	1.51	1.57
Pied flycatcher (Svartvit flugsnappare)	*Ficedula hypoleuca*	35	0.78	0.67	0.92
Jackdaw (Kaja)	*Corvus monedula*	35	0.78	3.29	1.29

Table 4-34. The fifteen most common nesting species in the Laxemar-Simpevarp area, presented as the total number of birds registered and the number of birds per km in transect surveys /Green 2005b/.

Species English (Swedish)	Latin	Total number (2004)	Abundance (n/km) 2004	Abundance (n/km) 2003	Abundance (n/km) 2002
Chaffinch (Bofink)	*Fringilla coelebs*	700	10.06	10.84	7.10
Willow warbler (Lövsångare)	*Phylloscopus trochilus*	471	6.77	3.41	7.15
Robin (Rödhake)	*Erithacus rubecula*	388	5.57	7.42	2.22
Song thrush (Taltrast)	*Turdus philomelos*	252	3.62	3.68	1.89
Blackbird (Koltrast)	*Turdus merula*	224	3.22	5.44	2.24
Great tit (Talgoxe)	*Parus major*	192	2.76	7.77	1.55
Siskin (Grönsiska)	*Carduelis spinus*	170	2.44	1.89	0.81
Starling (Stare)	*Sturnus vulgaris*	163	2.34	0.40	0.49
Wood pigeon (Ringduva)	*Columba palumbus*	157	2.26	2.62	1.63
Goldcrest (Kungsfågel)	*Regulus regulus*	131	1.88	1.44	0.38
Yellowhammer (Gulsparv)	*Emberiza citrinella*	106	1.52	1.59	0.87
Green finch (Grönfink)	*Carduelis chloris*	89	1.28	0.98	0.29
Blue tit (Bålmes)	*Parus caeruleus*	86	1.24	4.71	0.58
Tree pipit (Trädpiplärka)	*Anthus trivialis*	80	1.15	0.37	1.71
Wren (Gärdsmyg)	*Troglodytes troglodytes*	72	1.03	0.42	0.67

Of the fifteen most frequent species in 2004 in the Forsmark and Laxemar-Simpevarp area, eleven species are the same at the two areas. In the Laxemar-Simpevarp area, there are no sea birds among the fifteen most common birds, while common gull (*Sw: Fiskmås*) and greylag goose (*Sw: Grågås*) are among the fifteen most common species in the Forsmark area.

More red-listed species (Swedish Red List 2005) were recorded in the Forsmark area than in the Laxemar-Simpevarp area. 29 possibly breeding red-listed species were recorded in the Forsmark area, of which lesser black-backed gull (*Sw: Silltrut*), red-backed shrike (*Sw: Törnskata*) and wryneck (*Sw: Göktyta*) are the thee most common /Green 2007/. In the Laxemar-Simpevarp area, 20 red-listed species were recorded, of which marsh tit (*Sw: Entita*), red-backed shrike (*Sw: Törnskata*) and nightjar (*Sw: Nattskärra*) are the three most common species /Green 2006a/.

Food web properties

The continuous monitoring of the breeding bird fauna in the Forsmark and Laxemar-Simpevarp area makes it possible to utilize site data to estimate biomass and consumption by breeding birds in the regional model areas.

Methodology

Bird biomass per unit area was calculated using information from bird inventories and consumption of carbon was estimated using the field metabolic rate (FMR) /Nagy et al. 1999/ for each species. The FMR is the total rate of energy conversion for a wild animal including basal metabolic rate (BMR), thermoregulation, locomotion, feeding, predator avoidance, reproduction, growth and other energy consuming activities /Truvé and Cederlund 2005/. The FMR is then converted into carbon by a conversion factor provided by /Humphreys 1979/.

Bird species, total number of individuals, biomass and habitats

Estimates of the bird species and the number of territories for each species were based on inventories of the regional model area during the breeding season for the Forsmark area 2002–2004 and the Laxemar-Simpevarp area 2003 and 2004 /Green unpubl./. The total number of individuals of each species was calculated by assuming that there were two adults (male/female) in each territory, multiplied by the number of territories. The body mass of the species was mainly taken from /Green unpubl./, but in some cases body mass was taken from the Danish ornithological association website /DOF 2007, www/. All biomasses are presented in Appendix 4. The biomass per unit area was calculated by multiplying the number of breeding individuals by the species-specific body mass.

The different bird species were divided into three groups depending on which habitat they mainly gather their food from: woodland, open land or water (Appendix 4). Territory abundance (territory m^{-2}) was calculated for each species by dividing the number of territories by their habitat area, i.e. the coverage of forest, open land (Table 4-35) or water area (Table 4-36) in the monitored area, instead of the total surface area of the regional model areas. The coverages of the two different land habitats were estimated from the digital vegetation map /Boresjö Bronge and Wester 2003/.The water area was divided into six categories according to the potential feeding preferences of different bird species (Table 4-36).

Food selection, breeding period, number of eggs and offspring

Food selection by different species was found on the website of the Swedish Ornithological Association /SOF 2007, www/ and the Danish Ornithological Association /DOF 2007, www/ and /Jonsson 1992/. The species were divided into five different functional groups according to their main food preference (Figure 4-33).

The breeding period in days was calculated based on the number of months (30 days for all months) given in /Jonsson 1992/ or on the website of the Swedish Ornithological Association. The breeding period varied between 120 days, for species migrating to the south of Sahara or a similar distance, and 365 days for non-migratory bird species. The number of eggs laid were found on the website of the Danish Ornithological Association /DOF 2007, www/. The number of offspring produced was estimated by assuming that 50% of the mean number of eggs laid for each species /DOF 2007, www/ would hatch and the offspring would survive and leave the nest /Reid et al. 2000/, and multiplying this number by the number of territories.

Table 4-35. The area (km^2) of woodland and open land in the Forsmark and Laxemar-Simpevarp areas /Boresjö Bronge and Wester 2003/.

		Woodland	Open land
Land (m^2)	*Forsmark*	36.0	14.5
	Simpevarp	13.6	22.0

Table 4-36. The area (km^2) of different potential feeding habitats in the Forsmark and Laxemar-Simpevarp areas. The sea area was categorized by depth, where sea 1 = 0–5 metres and sea 2 = 5–20 metres.

	Forsmark	Simpevarp
Lakes	3.3	3.2
Lakes + sea 1	23.0	24.0
Lakes + sea 1,2	86.0	92.0
Sea 1	20.0	21.0
Sea 1,2	83.0	89.0
Sea 2	63.0	68.0

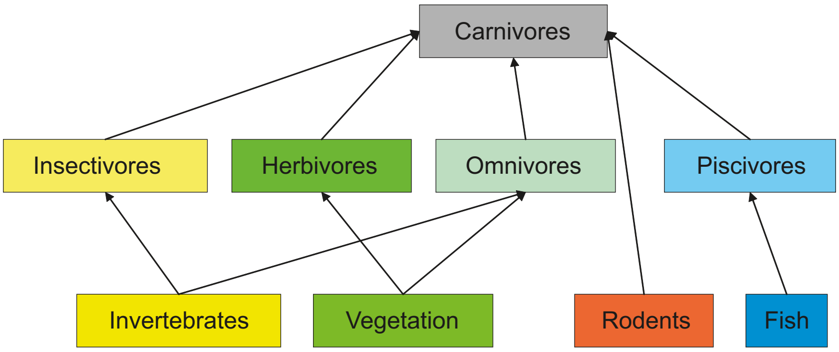


***Figure 4-33.** Schematic illustration of the food web categorization that was used to divide the bird species into five functional groups using their main food preference.*

Field metabolic rate calculations

The FMR estimations in kJ day^{-1} were calculated by using the equation by /Nagy et al. 1999/, which was based on adult and juvenile birds with the exception of nestlings. By utilizing the body mass it was possible to predict the daily food requirement of birds by using the equation:

$FMR = ax^b$

where x = body mass (g) and, a and b are known parameters /Nagy et al. 1999/ (a is the unconverted value of FMR (kJ day^{-1}) for a 1-g animal, and b is the slope of the log-log regression /Nagy 1987/). a and b were provided for the systematic/functional groups: passerines, Charadriiformes, Galliformes, marine birds, insectivores and omnivores and temperate forest birds. The group carnivores was assigned values representative for the category "All birds" in lieu of better estimates.

The annual food requirement for each bird species in the Forsmark and the Laxemar-Simpevarp areas was estimated by multiplying their daily FMR by the number of individuals and the breeding period in days. The same method for predicting the FMR was used for the offspring. Consumption for six months was calculated for offspring of bird species that remain over the winter, while consumption for only two months was calculated for offspring of migrating species. The FMR was then converted to total consumption of dry matter by dividing the FMR by the metabolizable energy in the specific food, which also includes the fraction that is egested (Table 4-37).

The carbon content of the food was then calculated using the total energy content of different food sources /Golley 1961/ presented in Table 7-5 in /Truvé and Cederlund 2005/ and then converted into gC by using the conversion factor 45.8 /Humphreys 1979/. These calculations assumed that the carbon content of seeds for all herbivore food (0.46) and omnivores was the average of the carbon content of seeds and insects. By dividing the consumed carbon for each land and water type (Tables 4-18, 4-19), the consumption per square metre of woodland, open land and the six different water categories could be estimated.

Table 4-37. The metabolizable energy content of food for different functional bird groups from/ Nagy et al. 1999.

Functional group	Energy digestibility (kJ g^{-1} dry weight)
Carnivore*	16.2
Bird/reptile insectivore	18.0
Fish-eating bird	16.2
Herbivore	10
Omnivore	14

* Same values as for fish-eating birds.

Results

Biomass

The biomass estimates are representative for the beginning of the breeding season before the nestlings have left the nest and are presented in Table 4-38 for the Forsmark area and Table 4-39 for the Laxemar-Simpevarp area. Figures 4-34 and 4-35 are the resulting maps showing the bird biomass distributed in the landscape.

Consumption

Overall, consumption per unit area was higher in the Forsmark area compared with the Laxemar-Simpevarp area for all land categories except sea 1, which is the same, and open land, which is 50% lower in the Forsmark area (Tables 4-40, 4-41). The land class woodland has the highest consumption in both areas, but is more dominant in regard to both bird consumption per unit area and areal coverage. Figures 4-36 and 4-37 are the resulting maps showing the bird consumption distributed in the landscape. Even though this dataset only covers one year it will serve as an important input to ecosystem models, where fluxes of organic matter due to bird consumption can be evaluated in relation to other fluxes.

Table 4-38. The biomass of carnivorous, insectivorous, herbivorous, piscivorous and omnivorous birds in different habitats in the Forsmark area in gC m^{-2} based on the breeding period 2002–2004.

	Woodland	Open land	Water				
			Lakes	Lakes+Sea1	Lakes+Sea1,2	Sea1	Sea1,2
Carnivores	0.0002	0.0001	–	<0.0001	–	–	–
Insectivores	0.0018	0.0006	–	0.0005	–	–	<0.0001
Herbivores	0.0001	<0.0001	–	0.0112	–	–	–
Piscivores	–	–	–	0.0065	0.0030	–	0.0010
Omnivores	0.0029	0.0024	<0.0001	0.0026	–	0.0035	–
Total	0.0050	0.0031	<0.0001	0.0210	0.0003	0.0035	0.0011

Table 4-39. The biomass of carnivorous, insectivorous, herbivorous, piscivorous and omnivorous birds in different habitats in the Laxemar-Simpevarp area in gC m^{-2} based on the breeding period 2003–2004.

	Woodland	Open land	Water				
			Lakes	Lakes+Sea1	Lakes+Sea1,2	Sea1	Sea1,2
Carnivores	0.0001	0.0003	–	<0.0001	–	–	–
Insectivores	0.0012	0.0009	–	0.0003	–	–	<0.0001
Herbivores	<0.0001	0.0001	–	0.0116	–	–	–
Piscivores	–	–	–	0.0042	0.0001	–	0.0002
Omnivores	0.0023	0.0036	<0.0001	0.0017	–	0.0035	–
Total	0.0037	0.0048	<0.0001	0.0178	0.0001	0.0035	0.0002

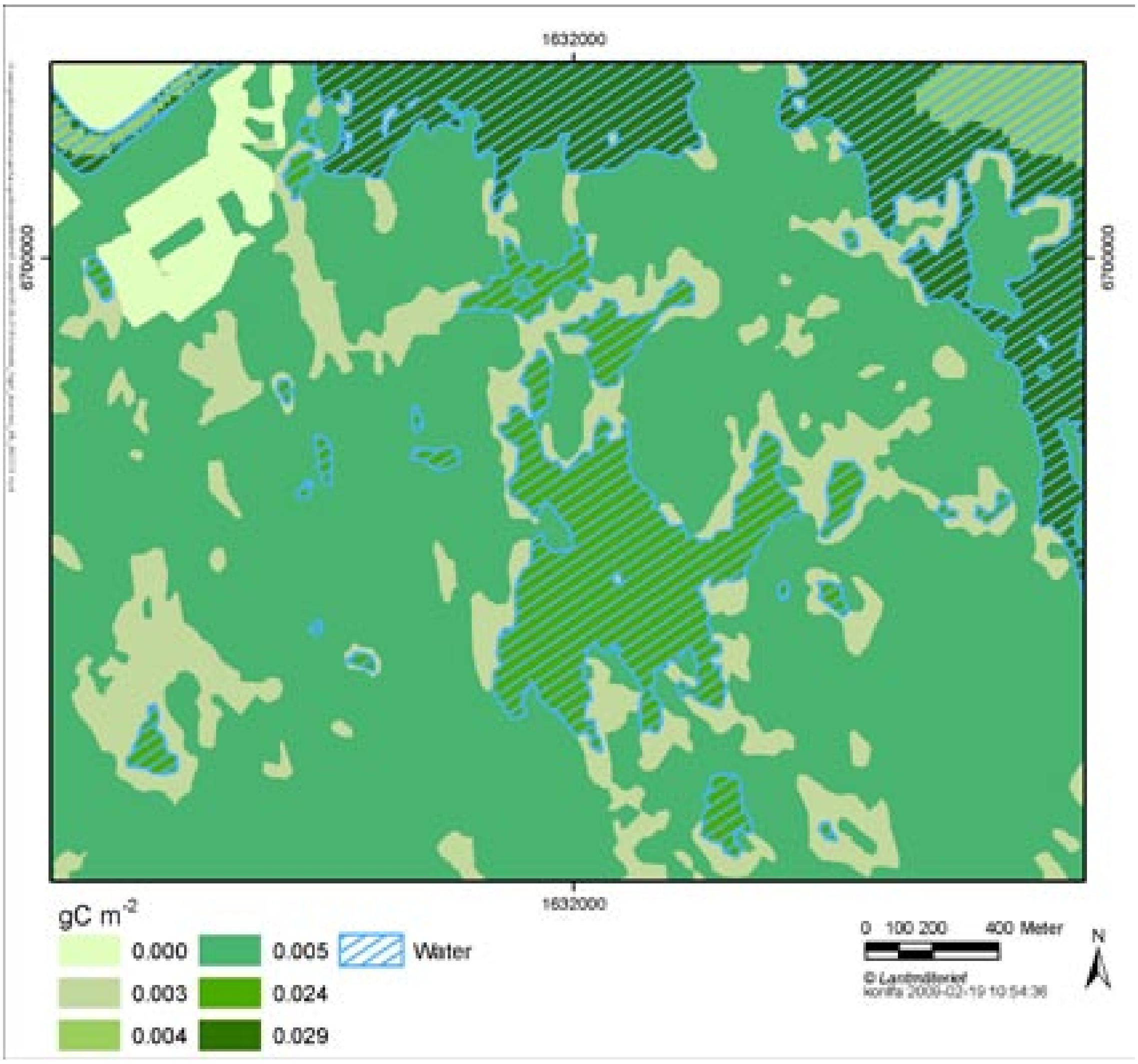


Figure 4-34. *An example from the Forsmark area, where the distribution of bird biomass as carbon is illustrated in one part of the regional model area. The areas with zero values are buildings or asphalt.*

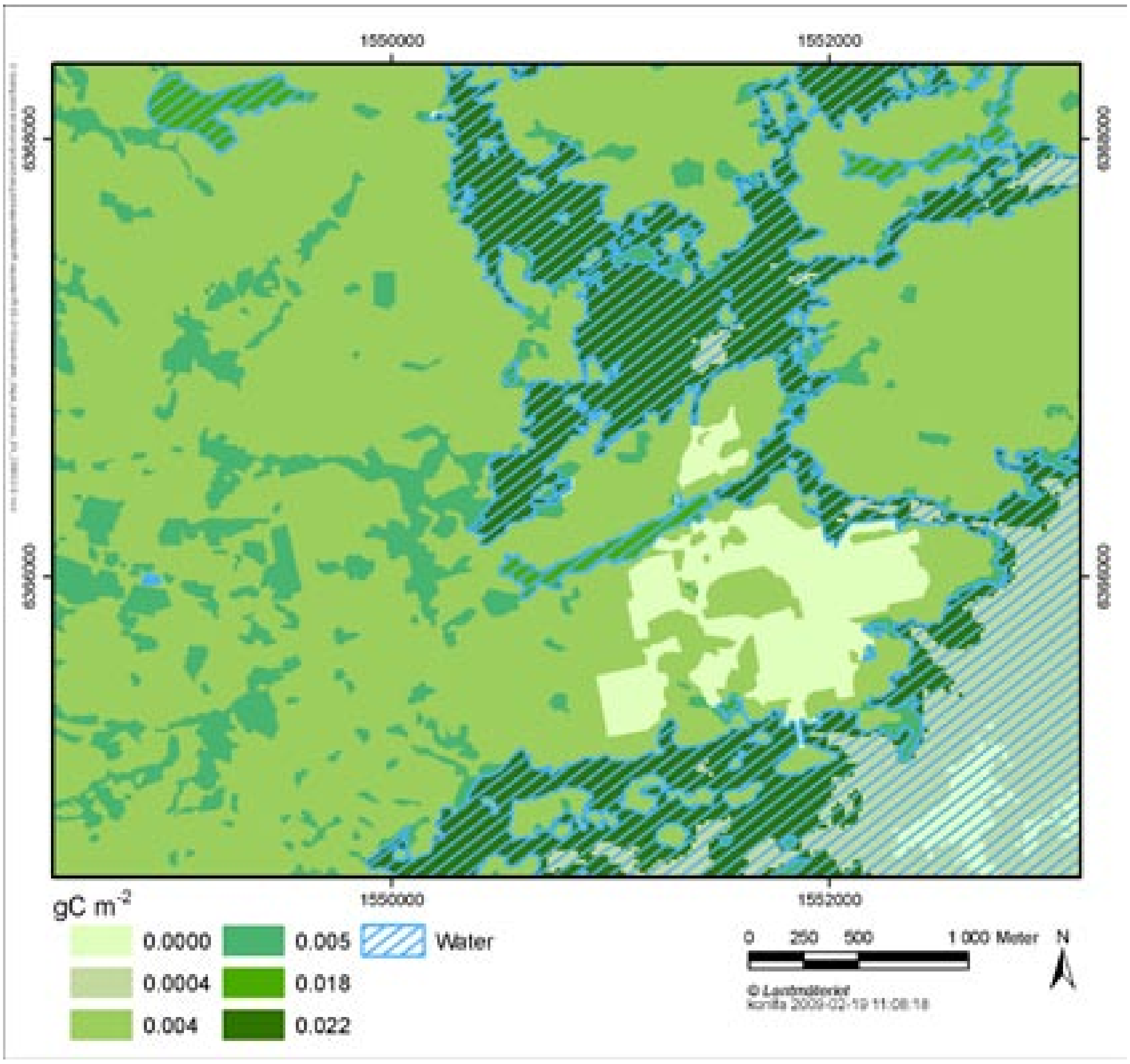


Figure 4-35. An example from the Laxemar-Simpevarp area, where the distribution of bird biomass as carbon is illustrated in one part of the regional model area. The areas with zero values are buildings or asphalt.

Table 4-40. The carbon consumption of carnivorous, insectivorous, herbivorous, piscivorous and omnivorous birds in different habitats in the Forsmark area in gC m^{-2} yr^{-1} based on bird densities in 2002–2004.

	Woodland	Open land	Water				
			Lakes	Lakes+Sea1	Lakes+Sea1.2	Sea1	Sea1.2
Carnivores	0.035	0.024	–	0.002	–	–	–
Insectivores	0.502	0.098	–	0.079	–	–	0.004
Herbivores	0.052	0.015	–	1.857	–	–	–
Piscivores	–	–	–	1.223	0.028	–	0.158
Omnivores	0.944	0.339	0.006	0.397	–	0.319	–
Total	1.53	0.48	0.01	3.56	0.03	0.32	0.16

Table 4-41. The carbon consumption of carnivorous, insectivorous, herbivorous, piscivorous and omnivorous birds in different habitats in the Laxemar-Simpevarp area in gC m^{-2} yr^{-1} based on bird densities in 2003–2004.

	Woodland	Open land	Water				
			Lakes	Lakes+Sea1	Lakes+Sea1.2	Sea1	Sea1.2
Carnivores	0.019	0.056	–	0.001	–	–	–
Insectivores	0.336	0.141	–	0.053	–	–	0.002
Herbivores	0.013	0.019	–	1.852	–	–	–
Piscivores	–	–	–	0.589	0.009	–	0.019
Omnivores	0.658	0.782	0.001	0.257	–	0.323	–
Total	1.03	1.00	0.001	2.75	0.01	0.32	0.02

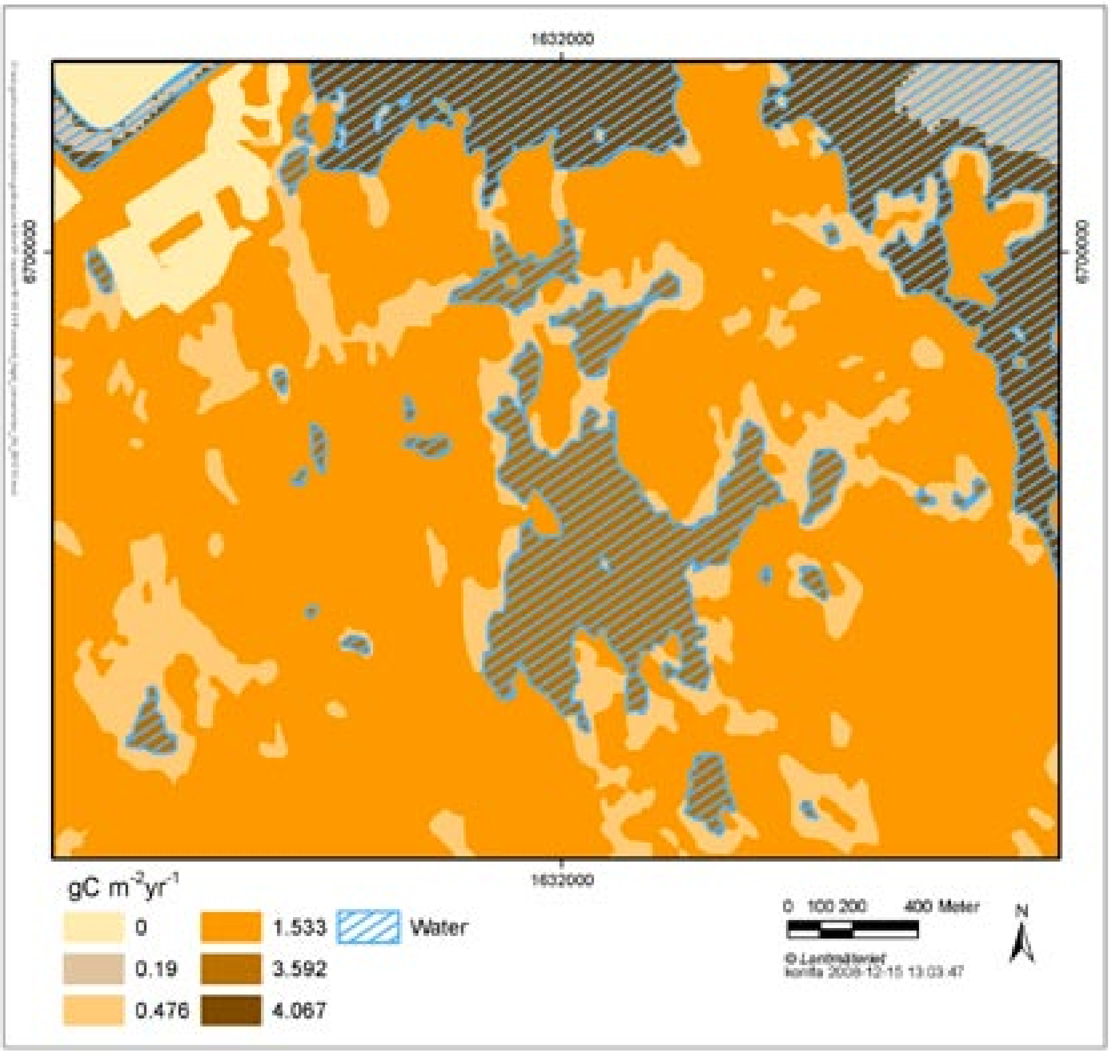


Figure 4-36. Bird consumption of carbon illustrated in one part of the Forsmark area. The areas with zero values are buildings or asphalt.

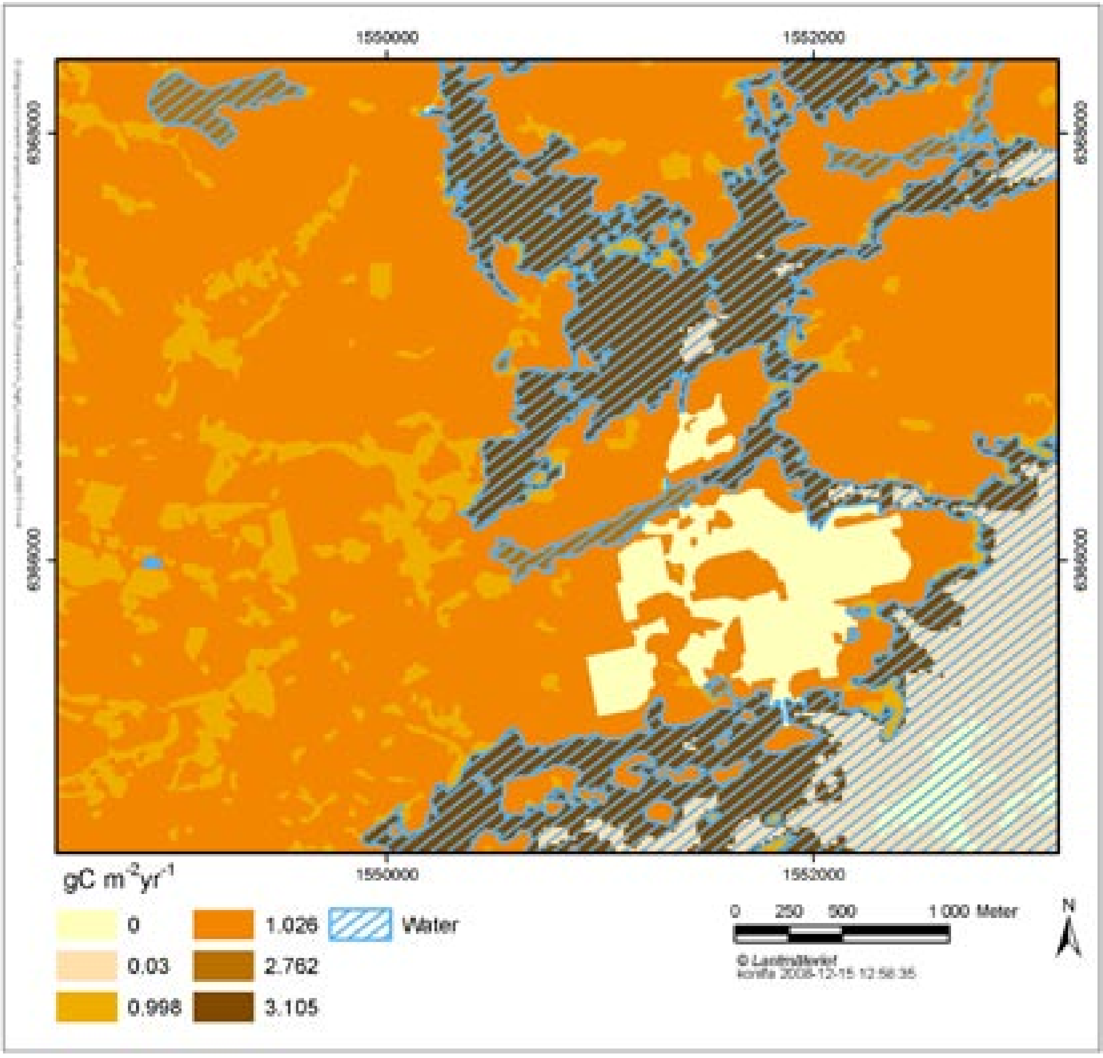


Figure 4-37. Bird consumption of carbon illustrated in one part of the Laxemar-Simpevarp regional model area. The areas with zero values are buildings or asphalt.

4.2.3 Amphibians and reptiles

Species and densities

For amphibians and reptiles, a short field study was performed primarily to verify the presence of suitable habitats for the Swedish species. It was carried out by following the smaller roads in the area and checking surrounding areas of special interest. The aim was to confirm the species that do occur in the Forsmark area and the Laxemar-Simpevarp area /Andrén 2004ab/. The densities have been estimated based on the performed surveys and generic data (see Appendix 5). Information describing some ecological data for amphibians and reptiles is compiled in Table 4-42.

Common frog and pool frog were only found in the Forsmark area. Both species are well known not to occur in Kalmar County. Pool frog habitat is unique, as it is dependent on land uplift and the continuous emergence of new land. Only a few localities of sand lizard in Sweden are doing well, so the record of sand lizard in the Laxemar-Simpevarp area was of special interest. It indicates a probable colony within the area, although this could not be confirmed.

Table 4-42. Ecological data concerning amphibians and reptiles applicable to the Forsmark and Laxemar-Simpevarp areas (see Appendix 5).

Species English (Swedish)	Weight (g)	Density (ind per km^2)	Diet	Energy needs (g dry weight per year)	Reproduction
Adder (huggorm)	150	100	Primarily mice and voles	330	On average 5 young per year
Grass snake (vanlig snok)	175	100 (200 in wetlands)	Frogs and toads, fish, newts	350	Approx. 13 eggs per year
Smooth snake (hasselsnok)	70	20	Other reptiles such as slow worm	140	On average 6 young per year
Slow worm (kopparödla)	15	1,000	Earthworms and snails	60	8 young per year
Common lizard (skogsödla)	5	500	Spiders and insects	21	7 young per year
Sand lizard [1] (sandödla)	8	15	Spiders and insects	27	10 eggs per year
Common frog [2] (vanlig groda)	25	2,000 (0–100 metres from pond) 1,000 (100–300 metres from pond) 500 (300–500 metres from pond)	Spiders and insects	28	2,000 eggs per year
Pool frog [2] (Gölgroda)	20	50–100 per pond (Four ponds in the Forsmark area)	Spiders and insects	17	1,700 eggs per year
Moor frog (åkergroda)	20	3,000 (0–100 metres from pond) 1,000 (100–300 metres from pond) 100–500 (300–500 metres from pond)	Insects, spiders and worms	20	1,500 eggs per year
Common toad (vanlig padda)	60	4,000	Insects, spiders and worms	123	4,000 eggs per year
Smooth newt (mindre vattensalamander)	3	2 per m^2 water area, the population size can be up to 10,000 individuals. They stay within 300 metres from the pond.	Larger zooplankton, water insects, water spiders, earthworms, snails and larvae of insects	3	350 eggs per year
Great creasted newt (stor vattensalamander)	9	1 per m^2 water area, the population is never larger than a few thousand individuals. They stay within 500 metres from the pond.	Insects, earthworms, snails, water insects, water spiders, larvae of frog and smooth newt.	8	200 eggs per year

[1] Only recorded in Laxemar-Simpevarp.
[2] Only recorded in Forsmark.

Spatial distribution

To be able to calculate the total carbon pools and fluxes of moor frogs and common frogs, the habitat area was defined and calculated in ArcGIS. The moor frog lives near small lakes, creeks, ponds and fens with slow-moving water, and its density varies with distance from a pond (Table 4-43, Table 4-44). The frog habitats in the two investigation areas were calculated based on the lakes and open wetlands (fens or wetter wetlands) in the area, using the topographic map in Forsmark and the vegetation map /Boresjö Bronge and Wester 2003/ in Laxemar-Simpevarp. Buffer zones were created around the lakes and wetter wetlands, giving three habitat zones of 0 to 100 m, 100 to 300 m and 300 to 500 metres from a lake or wetter wetland. As the wetlands in Forsmark area are dominated by drier mires (only 7% of the mires are wetter mires), the frog habitats in Forsmark area were calculated based on the lakes solely. Buffers were created around the lakes, creating three habitat areas: 0–100 m, 100–300 m and 300–500 metres distance from a lake. The moor frog and common frog habitats within the Forsmark area are illustrated in Figure 4-38, while the moor frog habitats in the Laxemar-Simpevarp area are illustrated in Figure 4-39.

The habitat of the Common toad has been assumed to be equal to the land area, excluded the most driest biotopes, i.e. pine forest, hard surfaces and coastal rocks These biotopes represent 35% of the land area in the Forsmark area and 34% in the Laxemar-Simpevarp.

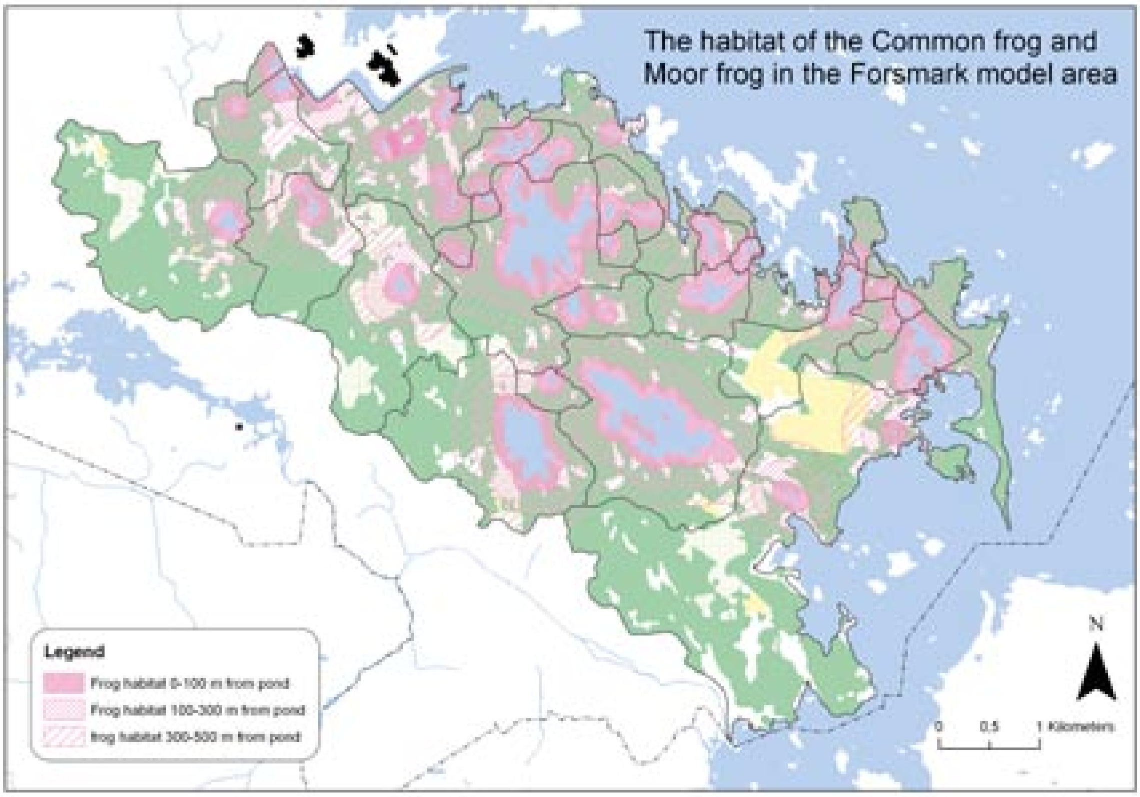


Figure 4-38. *Distribution of Moor frog and common frog habitat in the Forsmark area.*

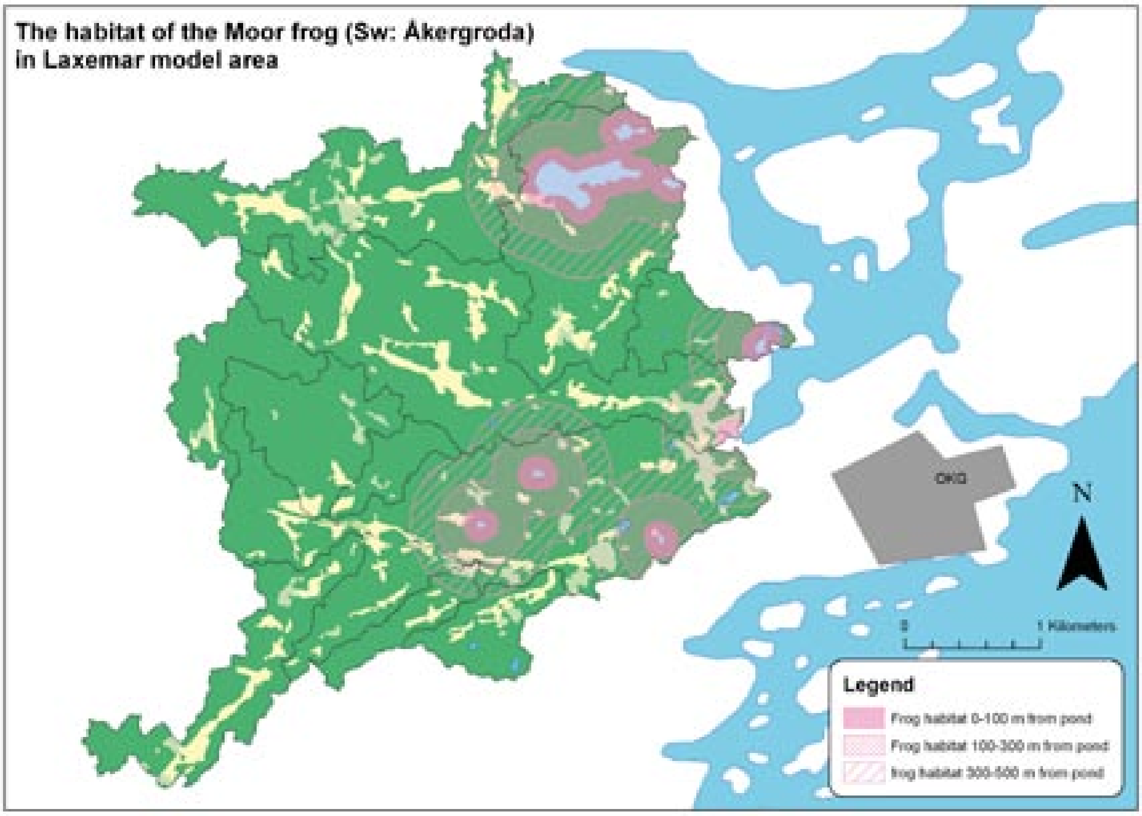


Figure 4-39. *Distribution of Moor frog habitat in the Laxemar-Simpevarp area.*

Food web properties

Generic densities for the species that occur in the Forsmark and Laxemar-Simpevarp areas have been estimated and are reported in Appendix 5. Average body mass as well as feeding habits and number of eggs/youngsters per individual are also included (see Table 4-22). No attempt has been made to calculate the production from the number of eggs/youngsters per female. Instead the production of the amphibians and the reptiles, as well as the egestion and respiration, have been calculated based on /Jerling et al. 2001, Table 2-4/, showing that the production of vertebrates (ectothermal, *Sw: växelvarma*) represent 8% of the energy input (consumption), while egestion represents 20% and respiration 72%.

The biomasses have been calculated with the assumption that the carbon content of amphibians and reptiles is 11.7% of the fresh weight (same as for mammals, Section 4.2.1). Reptiles are carnivores and their diet (small mammals, amphibians, other reptiles, insects and invertebrates) was assumed to contain 11.7% carbon (same as for mammals, see above). Amphibians eat insects and invertebrates.

The results of annual pools and fluxes in the Forsmark and Laxemar-Simpevarp areas are presented in Tables 4-43 and 4-44.

4.2.4 Invertebrates

Invertebrates represent a major component of the biodiversity and function of ecosystems. They have often been neglected in ecosystem studies /Weisser and Siemann 2004/. In the site descriptions, mainly invertebrate have effects on ecosystem function as detrivory and bioturbation been considered, although a number of mutualistic interactions, such as pollination, and food-web interactions, are important in different ecosystems. The studies related to invertebrates are briefly described below. No studies have been carried out at the sites in order to describe invertebrate herbivory, but a brief overview with some figures from the literature is presented and discussed below.

Table 4-43. General figures per unit area for densities, biomass, production, consumption, egestion and respiration for the amphibians and reptiles in the Forsmark area.

Species		Habitat	Density	Biomass (standing stock)		Production	Consumption	Egestion (Faeces)	Respiration
			Number per km^2	Body mass g ind^{-1}	Biomass mgC m^{-2}	mgC $m^{-2}\ y^{-1}$	mgC $m^{-2}\ y^{-1}$	mgC $m^{-2}\ y^{-1}$	mgC $m^{-2}\ y^{-1}$
Reptiles	Adder	Forest+Field	100	150	1.8	1.2	15	3.0	11
	Grass snake	Forest+Field	100	175	2.0	1.3	16	3.1	11
	Smooth snake	Forest+Field	20	70	0.2	0.1	1.3	0.3	0.9
	Slow worm	Forest+Field	1,000	15	1.8	2.2	27	5.4	19
	Common lizard	Forest+Field	500	5	0.3	0.4	4.7	0.9	3.4
Amphibians	Common toad	Habitat amphibians	4,000	60	28	18	221	44	159
	Moor frog	0–100 m from pond	3,000	20	7	2.2	27	5.4	19
		100–300 m from pond	1,000	20	2.3	0.7	9.0	1.8	6.5
		300–500 m from pond	300	20	0.7	0.2	3	0.5	2
	Pool frog	50–100 per pond (four in Forsmark)	75	20	0.2	0.05	0.7	0.1	0.5
	Common frog	0–100 m from pond	2,000	25	6	1.4	18	3.6	13
		100–300 m from pond	1,000	25	2.9	0.7	9.0	1.8	6.5
		300–500 m from pond	500	25	1.5	0.4	4	0.9	3

Table 4-44. General figures per unit area for densities, biomass, production, consumption, egestion and respiration for the amphibians and reptiles in the Laxemar-Simpevarp area.

Species		Habitat	Density	Biomass (standing stock)		Production	Consumption	Egestion (Faeces)	Respiration
			Number per km^2	Body mass g ind^{-1}	Biomass mgC m^{-2}	mgC $m^{-2}\ y^{-1}$	mgC $m^{-2}\ y^{-1}$	mgC $m^{-2}\ y^{-1}$	mgC $m^{-2}\ y^{-1}$
Reptiles	Adder	Forest+Field	100	150	1.8	1.5	19	3.8	14
	Grass snake	Forest+Field	100	175	2.0	1.6	20	4.0	14
	Smooth snake	Forest+Field	20	70	0.2	0.1	1.6	0.3	1.1
	Slow worm	Forest+Field	1,000	15	1.8	2.7	34	6.8	25
	Common lizard	Forest+Field	500	5	0.3	0.5	6.0	1.2	4.3
	Sand lizard	Forest+Field	15	8	0.01	0.02	0.2	0.05	0.2
Amphibians	Common toad	Habitat amphibians	4,000	60	28	22	281	56	202
	Moor frog	0–100 m from pond	3,000	20	7.0	2.7	34	6.8	25
		100–300 m from pond	1,000	20	2.3	0.9	11.4	2.3	8.2
		300–500 m from pond	300	20	0.7	0.3	3.4	0.7	2.5

Soil fauna

Detrivory is generally practiced by the soil fauna, accounting for approximately 10% of the carbon turnover in soil, and the fungi and bacterial flora, accounting for approximately 90% (T Persson 2004, pers. comm.). The soil fauna is instead of greater importance to the soil structure and soil properties, e.g. bioturbation (see below). The main part of the soil fauna consists of microbivores (they consume microorganisms), while some species are primary decomposers (T Persson 2004, pers. comm.). According to /Jerling et al. 2001/, production by microbivores is 12% of the energy input (consumption), while respiration accounts for 18%. The rest leaves as faeces (70%).

Density and biomass may vary depending on habitat and Table 4-45 lists the occurrence of some important taxa. The biomass was approximately six times lower in the pine forest than in the deciduous forest, and the highest biomass was found in the grassland. In general, deciduous forests with moderately high to high pH have mull soils without a distinct humus layer. Typical mull soils indicate the presence of burrowing earthworms. Acid coniferous forests lack deep-burrowing earthworms, and these forests are characterized by a mor (raw humus) layer lying on top of the mineral soil. Some of the spruce forests in the Forsmark area had high pH and allowed deep-burrowing earthworms to mix the soil and form a mull-like soil. The abundance of medium-sized soil animals (mesofauna) is normally higher in coniferous than in deciduous forests (Table 4-45). These animals (springtails and oribatid mites) largely feed on fungal mycelia, which are the main decomposer organisms in coniferous forest soils, whereas bacterial decomposition is dominant in deciduous forest soils with high pH. Among the soil organisms, fungi probably have the greatest storage capacity for radionuclides (T Persson, pers. comm.).

Table 4-45. Biomass and density in the soil fauna in three different biotopes /Lohm and Persson 1979/.

Species	**Deciduous forest (Uppland)**			**Pine forest (Gästrikland)**			**Grassland (Uppland)**		
English or Latin (Swedish)	**Number per m^2**	**Dry weight per m^2 (mg)**	**mgC per m^2**	**Number per m^2**	**Dry weight per m^2 (mg)**	**mgC per m^2**	**Number per m^2**	**Dry weight per m^2 (mg)**	**mgC per m^2**
Earthworms (daggmask)	180	6,100	3,050	< 1	17	8	130	5,900	2,950
Enchytraeidae (småringmask)	3,800	370	185	17,000	420	210	24,000	850	425
Wood lice (gråsuggor)	2	9	5	< 1	2	1	< 1	4	2
Centipede (tusenfotingar)	1,200	70	35	25	3	2	2	30	15
Springtails (hoppstjärtar)	66,000	110	55	65,000	100	50	110,000	140	70
Protura (trevfotingar)	3,800	2	1	1,000	1	1	40	1	0
Thrips (tripsar)	100	1	0	1,400	6	3	720	3	2
Homoptera (växtsugare)	70	2	1	270	11	6	70	1	1
Heteroptera (skinnbaggar)	10	7	4	190	10	5	10	3	2
Beetles (skalbaggar)	600	480	240	500	170	85	1,400	2,800	1,400
Hymenoptera (steklar)	50	50	25	40	15	8	110	3	2
Midge larvae (mygglarver)	1,300	50	25	700	20	10	4,400	320	160
Fly larvae (fluglarver)	30	80	40	70	9	5	1,100	330	165
Spiders (spindlar)	220	70	35	340	70	35	200	40	20
Mites (kvalster)	190,000	600	300	620,000	400	200	110,000	130	65
Sum	267,362	8,001	**4,000**	706,535	1,254	**627**	252,182	10,555	**5,277**

Bioturbation

/Persson et al. 2007/ studied the quantitative impact of earthworms and ants on bioturbation of soil in different ecosystems at a total of 10 localities in the Forsmark and Laxemar-Simpevarp area. Earthworms were sampled in four 20×20 cm sub-plots at each site and were determined, dried and weighed in the laboratory. Gut passage time and faeces production were determined in a laboratory experiment at constant temperature, and temperature dependence of earthworm growth was also studied. Ant species composition, ant nest density and nest volume were investigated in the field by using pitfall traps and a transect method to enumerate ant nests. Dry weights of ant nests were determined after weighing in the laboratory.

Earthworm bioturbation was found to be in the range 0.0003 to 25 kg dry weight m^{-2} y^{-1} among the ten localities. Ant bioturbation was markedly lower than earthworm bioturbation and was mainly caused by *Myrmica* species. Ant bioturbation varied between 0.004 and 0.5 kg dry weight m^{-2} y^{-1}. Thus, the ants generally contributed 0–2% of total bioturbation with the exception of an abandoned field in the Forsmark area (12%) and the acid spruce forests in the Laxemar-Simpevarp area (93%), which had low earthworm populations.

Earthworm abundances, biomasses and turnover of soil were markedly dependent on site characteristics, both in the Forsmark and the Laxemar-Simpevarp area. There was a positive correlation between pH and abundance of earthworms in the Laxemar-Simpevarp area. In the Forsmark area, where the soils are generally rich in $CaCO_3$, soil pH was often close to 7 except for the litter and humus layers in some coniferous forests. Some of the localities in the Forsmark area had high groundwater tables, and this fact can explain reduced figures of earthworm bioturbation. No significant correlation was found between pH and abundance of ant nests. Total bioturbation estimated for earthworms and ants was between 0.3 (spruce forest on drained peatland) and 247 tonnes dry weight ha^{-1} y^{-1} (deciduous oak forest). /Persson et al. 2007/ concluded that bioturbation, especially by earthworms, can be remarkably high. A normal stone-free mull soil contains about 300 kg dry weight m^{-2} (3,000 tonnes ha^{-1}) in the top 30 cm. Earthworms and ants can thus turn over the topsoil in 12–20 years in suitable habitats.

Soil respiration

The flux of carbon (CO_2) from the soil, i.e. soil respiration, can be divided into autotrophic respiration (by roots) and heterotrophic respiration (by microbes, microfauna and fungi). It is the heterotrophic components that are responsible for decomposition. During decomposition of dead plant, animal and microbial material, the organic matter is converted into inorganic nutrients and CO_2. The balance between decomposition and NPP strongly influences the carbon cycle on both the ecosystem and global scales.

Methods

Soil respiration was measured in 2005 and 2006 in the Forsmark area /Heneryd 2007b/ and in 2004 /Tagesson 2006bc/ and /Lundkvist 2006/ in the Laxemar-Simpevarp area for a number of different vegetation types (Table 4-46). The measurements were made over the space of a year to include the different seasons using permanent plots within each vegetation type. Measurements of the CO_2 flux from the ground were performed using a closed chamber technique, along with measurements of air and soil temperature /Tagesson 2006d/. Annual soil respiration was estimated using a regression approach, where the relationship between air temperature (logged every 30 minutes at the site) and soil temperature and measured soil respiration was used. Soil moisture was measured for 6 vegetation types in the Laxemar-Simpevarp area /Tagesson 2006bc/, but was not included in the regression due to low explanatory power /Tagesson and Lindroth 2007/ and was not included in the calculations for the other vegetation types. The soil-temperature-modelled soil respiration generally showed higher values, which is probably an effect of a more fluctuating diurnal air temperature. The soil temperature is less prone to fluctuations due to its temperature-buffering capacity. The figures presented here describe only the soil-temperature-modelled soil respiration. The carbon flux measurements also made it possible to model GPP and calculate the net ecosystem exchange (NEE) from the soil and field layer, which is also presented below.

Results and discussion

Soil respiration

There was large seasonal variation in modelled soil respiration. Both air-temperature- and soil-temperature-based models peaked in July. The pastures and the semi-natural grassland show a very similar value for soil respiration, which is high compared with other studies, e.g. /Maljanen et al. 2001/, reported as 760 gC m^{-2} y^{-1} for an organic field in eastern Finland. However, the highest value (1.15) was found on a semi-natural grassland situated on peat soil that had been drained. Similarly, most agricultural land in Laxemar-Simpevarp area has peaty soils originating from an earlier stage as a wetland which start to oxidize when the water table is lowered.

The span of annual soil respiration for the coniferous forests (580–1,150 gC m^{-2} y^{-1}) is large where the low value is from an even-aged Norway spruce forest with a thin soil layer, whereas the high value is from a 100-year-old well-managed Scots pine forest on a deep soil layer. This span fits reasonably well the span from other investigations in the boreal region (see discussion in /Tagesson 2007/).

The range for deciduous forest (470–1,180 gC m^{-2} y^{-1}) embraces the mean for temperate forests of 650 gC m^{-2} reported by /Raisch and Schlesinger 1992/. The low value is from an open low-density forest subjected to regular grazing by cattle. Other studies have also reported high soil respiration for similar vegetation types, e.g. 820–1,210 gC m^{-2} y^{-1} /Bolstad et al. 2004/.

Clear-cuts or young coniferous forests are expected to have high soil respiration due to remaining woody debris, such as stumps and roots. /Kolari et al. 2004/ estimated total ecosystem respiration for differently aged stands and reported that soil carbon effluxes were largest for 12-year-old stands. Both estimates are in the upper range of the respective site.

Wetland soil respiration is expected to be lower due to more or less anaerobic conditions /Heal et al. 1981/, but both estimates are rather high in comparison to estimates for a swampy mixed hardwood stand in the Harvard forest in Massachusetts of 140 gC m^{-2} y^{-1} /Davidson et al. 1998/. Others have found higher values, i.e. 396 gC m^{-2} y^{-1} from May to October 1996 for a boreal black spruce forest in Saskatchewan /Swanson and Flanagan 2001/. /Davidson et al. 1998/ explained their low values not only as caused by wetness, but also due to low input of C to the soil. In the Harvard stand in Massachusetts, trees are sparse so NPP is low as well, whereas in the Forsmark and Laxemar-Simpevarp areas trees are dense /Tagesson 2006a/, consisting of only deciduous trees and a high proportion of deciduous trees, respectively, and consequently a high C input to the soils.

The poor fen was in a similar range as other studies done in mires and fens. in the Nordic countries, estimated values varied between 214 and 456 gC m^{-2} y^{-1}, where the low value was from Kaamanen in the northern subarctic regions of Finland /Lindroth et al. 2007/ and the high value was from Fäjemyren, close to Hässleholm in the southern parts of Sweden.

The standard deviations in Table 4-46 are large, reflecting the large spatial variation between the plots within each ecosystem. The three localities lacking a tree layer and having fairly uniform soil conditions (excluding the poor fen) all show a similar lower standard deviation.

GPP and NEE

GPP by the field and bottom layer vegetation in the poor fen (700 gC·$m^{-2}y^{-1}$) is high compared with other fen studies in the Nordic countries with values between 250 and 480 gC·$m^{-2}y^{-1}$ /Lindroth et al. 2007/. Some of these ecosystems were situated further north, and the lower GPP may reflect a shorter vegetation period. One of the study sites, Fäjemyren (480 gC·$m^{-2}y^{-1}$), was at a similar

Table 4-46. Annual soil respiration and standard deviation in kgC m^{-2} y^{-1} using soil-temperature-based models for the Forsmark and Laxemar-Simpevarp areas from /Tagesson 2006b, 2007/.

Site/Vegetation type	SKB ID Code	Year	Soil type /Lundin et al. 2004, 2005/	Mean	SD
Forsmark area					
Pasture	AFM001257/AFM001081	2005/06	RG/GL-a	1.09	0.75
Norway spruce 1	AFM001258/AFM001068	2005/06	RG/GL	0.79	1.24
Norway spruce 2	AFM001259/AFM001247	2005/06	RG/GL / LP	0.58	0.25
Deciduous forest	AFM001260/AFM001071	2005/06	GL/CM	0.47	0.37
Clear-cut (20 y Scots pine)	AFM001261	2006	–	0.71	0.54
Forested wetland (*Picea*/*Alnus*)	AFM001263/AFM001076	2006	GL	0.45	0.38
Laxemar-Simpevarp area					
Semi-natural grassland	ASM001430	2004/05	UM/GL	1.15	0.71
Scots pine (deeper soil)	ASM001429	2004/05	PZ/RG	1.17	0.93
Lichen/outcrop (thin soil)	ASM000210	2004/05	LP	0.75	1.39
Norway spruce (drained peatland)	ASM001440	2004/05	HI-f	0.85	0.80
Pedunculate oak 1	ASM001426	2004/05	UM/RG	1.18	0.98
Pedunculate oak 2	ASM001427	2004/05	UM/RG	0.78	0.85
Poor Fen	ASM001443	2006	HI-f	0.99	1.84
Pasture	ASM000015	2006	UM/GL	1.08	0.56
Clear-cut (20–25 y Scots pine)	ASM000016	2006	PZ/RG	1.30	1.76
Forested wetland (*Alnus*)	ASM001434	2006	HI-f	0.73	0.62

latitude as the Laxemar-Simpevarp area, but other factors also influence GPP, such as nutrition, microclimate, biomass, species etc. GPP by ground vegetation in the agricultural field (dominated by grass and herbs, Table 4-46) (710 gC m^{-2} y^{-1}) is similar to that in other grassland studies with values between 270 and 1,210 gC m^{-2} y^{-1} /Flanagan et al. 2002, Suyker and Verma 2001, Suyker et al. 2003, Novick et al. 2004/.

NEE for the poor fen was between –290 and 320 gC m^{-2} y^{-1}, suggesting that there was no net carbon uptake or loss during the measured year. This is similar to other studies; in Fäjemyren there was a net uptake of 20 gC m^{-2} y^{-1} /Lund et al. 2007/. In Kaamanen, Siikaneva and Degerö, NEE was between 30 and 0 gC m^{-2} y^{-1} /Lindroth et al. 2007/. NEE in the agricultural areas indicate that there is net loss of carbon (on average –190 gC m^{-2} y^{-1}) to the atmosphere. Other studies have obtained a wide range of NEE estimates (–950 to 274 gC m^{-2} y^{-1}) /Suyker et al. 2003, Flanagan et al. 2002, Novick et al. 2004, Maljanen et al. 2001, Byrne et al. 2005, Soegaard et al. 2005, Hollinger et al. 2005/.

Table 4-47. Modelled GPP for the field layer using photosynthetically active radiation (PAR). Net ecosystem exchange (NEE) was calculated from the modelled soil respiration from three vegetation types in the Laxemar-Simpevarp area. From /Tagesson 2006b and 2007/.

Vegetation type	SKB ID Code	Year	GPP (kgC m^{-2} y^{-1})	NEE (+/– is gain/loss) (kgC m^{-2} y^{-1})
Seminatural grassland	ASM001430	2004/2005	0.54±0.36	–0.66 and –0.38
Pasture	ASM 000015	2006	0.71±0.27	–0.38 and 0.00
Poor Fen	ASM 001443	2006	0.70±0.17	–0.29 and 0.32

Herbivory

The total biomass of insects appears to be small compared to the plant biomass. For example, in an IBP study of a meadow-steppe in central Russian, above- and below-ground invertebrate biomass was equivalent to about 10% of the annual plant production (11–14 tons dw/ha) /Zlotin and Khodashova 1980/. More than 90% of the animal biomass was found below ground, and earthworms accounted for 94% of the soil animal biomass or 80–90% of total animal biomass. The biomass of above- and below-ground insects constituted less than 2% of the animal biomass or 0.2% of the plant production on the same meadow-steppe. Biomass does not generally entail a prominent role for insects in nutrient cycling /cf. Petrusewicz 1967, Schowalter 2000/. This is a reason why insects are often not considered to be very important for nutrient cycling. A second reason is that the average proportion of net primary productivity (NPP) consumed by herbivorous insects is 10% or less, except in outbreak situations /e.g. Detling 1988, Coupe and Cahill 2003/, while large mammalian herbivores, such as African mammals, are known to consume up to 90% of savannah NPP /Detling 1988/.

Direct effects of insects on ecosystem functioning include reduction of NPP by herbivores and breakdown of litter by detrivores. Perhaps one of the most important roles for the soil fauna is to physically break up organic matter in soil and make it accessible to fungi/bacteria. They thereby have a major impact on below-ground processes and nutrient cycling, usually by changing the soil structure and decomposition and mineralization rates /Jones and Bradford 2002/. Indirect effects include changes in matter fluxes due to changes in plants species composition that are mediated by insect herbivory.

Above ground

Herbivory by insects on Scots Pine (*Pinus sylvestris*) was estimated to be 0.7% of the total needle biomass and 2.5% of the total needle production during one year in central Sweden /Larsson and Tenow 1980/. A review of herbivory showed that herbivores generally consume less than 10% of NPP in forests, except during insect outbreaks, when herbivory can be up to 50% of NPP /Schowalter et al. 1986/. Another review came to the conclusion that on average, in terrestrial systems, only 18% of plant biomass is consumed by vertebrate and invertebrate herbivores /Cyr and Pace 1993/. /Mattson and Addy 1975/ tried to take a "forest-wide" perspective, taking several parameters into account. They estimated that insect herbivores consume on average around 10% of the total NPP in forests. The potential roles of insects in ecosystems are less well characterized above ground, but in some systems at least they may have dramatic, although often temporary, effects on primary production via intense grazing pressure /Schowalter et al. 1986, Dyer et al. 1993/.

Below ground

Root consumption by phytophagous nematodes was estimated to 0.3% of the annual production of fine roots in the Scots pine forest above /Magnusson and Sohlenius 1980/. In grassland systems, the plant production consumed by herbivores below ground may be between 3 and 7 times the amount consumed above ground /Scott et al. 1979/. Attempts to measure the impacts of herbivory on plant productivity are likely to be an underestimate because some of the effects of insect herbivores are relatively neglected /Hunter 2001/.

Root feeding limits plant uptake of water and nutrients, leading to a stress response being induced within the host plant. Such a response generally leads to the mobilization or translocation of soluble C and N to the foliage. Foliar herbivory generally leads to a reduction in root biomass /e.g. Crawley 1983/, largely due to C reallocation to sustain growth. Soil nematodes can play a beneficial role in C cycling in grassland ecosystems. Nutrient leaching due to low levels of nematode root herbivory led to enhanced microbial activity and microbial biomass and increased the allocation of photoassimilation to roots. If root herbivory can lead to a greater and more active soil microbial biota, then this in turn can lead to greater decomposition and mineralization, resulting in an increase in the availability of C and N for plant uptake. An alternative hypothesis is that a greater and more active soil biota, resulting from root herbivory, will lead to increased asymmetric competition between roots and microbes for nutrients (with microbes benefiting from the interaction).

4.2.5 Fungi

This section contains a brief description of fungi that have been found or been investigated at the sites. A more general discussion of mycorrhizas in an ecosystem perspective is found in Chapter 5, while estimates of the yield from edible fungi are presented in Section 4.3.2.

Species

/Abrahamsson 2003/ and /Andersson 2004/ made a brief inventory of fungi in a few localities at both sites, mainly searching for red-listed species and species regarded as indicators of conservation values. The species lists are presented in Appendix 6 and 7.

/Johanson et al. 2004/ investigated element uptake by fungi in the Forsmark area and compared the element content for 20 elements in the soil, the mycelia and the fruiting bodies from a number of fungi species found at four forest localities dominated by conifers (Table 4-48).

Table 4-48. C and N content in fungi fruiting bodies (% of dry weight) of different species of fungi collected in the Forsmark area from /Johanson et al. 2004/.

Species	C	N
Lactarius deterrimus	46.1	2.7
Suillus granulatus	46.7	2.6
Lactarius scrobiculatus	45.6	3.4
Boletus edulis	47.0	4.6
Cortinarius odorifer	45.5	3.6
Sarcodon imbricatus	45.1	4.4
Cantharellus tubaeformis	46.3	3.3
Lactarius trivialis	45.7	3.0
Cortinarius armeniacus	46.4	4.1
Cortinarius sp.	44.8	3.9
*Hypholoma capnoides**	43.4	4.0
Tricholoma equestre	42.5	2.1
*Collybia peronata**	44.7	5.1
Suillus variagatus	47.8	3.7
Suillus variagatus	46.4	4.4
Suillus variagatus	44.2	4.7
Mean	45.5	3.7
Median	45.6	3.8
SD	1.4	0.8

* Saprophytes

Mycorrhizas

Mycorrhizas are symbiotic relationships between plant roots and fungal hyphae. The plant obtains nutrients, mainly nitrogen and phosphorus, and in return the fungi are provided with carbohydrates, which is the major carbon source for these fungi. Data from diverse ecosystems indicate that more than 50% of the NPP is commonly allocated to below-ground plant parts. However, a significant proportion of carbon allocated below ground may be directed to mycorrhizal fungi /Read 1991/. The proportion of the total plant photosynthates that are allocated to ectomycorrhizal fungi has been reported to be 10–20% for arbuscular mycorrhizal fungi /Jakobsen and Rosendahl 1990/. Carbon transfer from vegetation through roots to fungi is of significant importance when describing the flow of carbon /Fitter et al. 2000/. Nutrient uptake by forest trees is greatly dependent on ectomycorrhizal (EM) fungi. Ectomycorrhizal fungi form an extensive mycelial network in the soil, which increases the absorbing surface area several-fold.

4.2.6 Confidence and uncertainties

Species inventories and population estimates

Intensive monitoring of the larger mammals and birds has resulted both in species lists and reliable population estimates from the sites. For other species, such as rodents and amphibians, there are estimates from the site, but not covering the same temporal scale. Overall, these species lists and population estimates has to be regarded as unique and best available to underpin further calculations of fluxes of matter in local food webs.

Consumption estimates

Studies of the field metabolic rates (FMRs) of free-living mammals and birds suggest that body mass is the primary determinant of energy and food requirements, which together with phylogeny accounts for 93–95% of the variation in log FMR /Nagy et al. 1999/. However, there is a considerable residual variation after antilog transformation that is expressed as a large confidence interval around FMRs predicted from body mass. The studies of FMR are based on doubly labelled water and are typically short-term studies, being sensitive to unusually energetic phases in an animal's life rather than being representative of a year. The FMRs that have been used to calculate the annual energy requirements of mammals and birds are the mean of a large number of studies, presented in /Nagy et al. 1999/. They are therefore considered to be fairly robust estimates.

Categorization of species according to food and habitat preferences

The categorization of species into functional groups according to their diet is in some cases difficult, since e.g. omnivores feed on a variety of different sources, although mainly insects and seeds. However, this categorization will reflect the major consumption and, accordingly, the major fluxes from the food sources to the different bird species, since it is based on their metabolic rate, so errors in the categorization of bird species into trophic levels will not cause an under- or overestimation of the actual consumption. The categorization of bird species into woodland and open land based on their feeding or nesting preferences is perhaps even more difficult, since some of the species feed in both forested and open habitats or feed in different habitats in the breeding and winter seasons. Classifying birds species as belonging to different habitats according to their food or nesting preferences is important to be able to determine whether some of the categories are more exposed to bioavailable contaminants, such as radionuclides, than others.

4.3 Land use

4.3.1 Land use classes at the landscape level

This is a general overview of different land use at the two sites. Land use has been treated in greater detail within the descriptions of the vegetation types wetland, agricultural land and forests above.

The Forsmark area

Land use in the Forsmark area (area definition in /Miliander et al. 2004a/) differs from the average land use in Uppsala County (see Table 4-49). The agricultural area in the Forsmark area is only 4% of the total area, considerably lower than in Uppsala County, where it represents 25%. Furthermore, only 0.04% of the land area consists of urban areas (developed areas), compared with 4.9% in Uppsala County. On the other hand, there are far more forests, wetlands and lakes in the Forsmark area. The forest area represents as much as 72.5% of the land area.

The Laxemar-Simpevarp area

Land use in the Laxemar-Simpevarp area (area definition in Miliander et al. 2004b) differs from the average land use in Kalmar County (Table 4-50). The forest area is far more dominant in the Laxemar-Simpevarp area than in Kalmar County. The amount of arable land and other landscape types is considerably less in the Laxemar-Simpevarp area.

Table 4-49. Land use in Uppsala County and the Forsmark area /Miliander et al 2004a/.

Type of land use	Uppsala county		Forsmark area	
	Area (hectares)	Percentage distribution (%)	Area (hectares)	Percentage distribution (%)
Agricultural land	179,940	25.1		
Arable land			34	1.7
Grazing land			50	2.6
Forest	401,500	55.9	1,411	72.5
Developed	34,900	4.9	0.7	0.04
Pits, mines etc	250	0	0	0
Wetlands -mire	17,000	2.4	206	10.6
Bare rocks, high mountains, other	65,320	9.1	67	3.4
Water	19,380	2.7	163	8.4
Unknown			14	0.7
Total	**718,290**	**100**	**1,946**	**100**

Source: Land area in Uppsala County from the report Markanvändning i Sverige, Table 5 /SCB 1998/. The agricultural area is not divided into arable and grazing area. Calculated: Land area in the Forsmark area from Vegetation Classification /Boresjö Bronge and Wester 2003/.

Table 4-50. Land use in Kalmar County and the Laxemar-Simpevarp area /Miliander et al. 2004b/.

Type of land use	Kalmar county		Laxemar-Simpevarp area	
	Area (hectares)	Percentage distribution (%)	Area (hectares)	Percentage distribution (%)
Arable land	134,878	12	556	4.4
Grazing land	53,007	4.5	465	3.7
Forest	728,605	62	11,251	89
Developed	18,551	1.6	125	1.0
Water	49,470	4.2	268	2.1
Other (wetlands bare rocks, pits etc.)	182,049	16	41	0.3
Total	**1,166,560**	**100**	**12,706**	**100**

Source: Land area for Kalmar län from the report Markanvändningen i Sverige (SCB, 1998), table B24. Calculated: Land area for Laxemar-Simpevarp area from Vegetation Classification /Boresjö Bronge and Wester 2003/.

Conclusions and comparison

The two areas have a somewhat similar land use distribution. They are both dominated by commercial forestry, whereas agricultural activity is limited. Agricultural activity is more prevalent in the Laxemar-Simpevarp area than in the Forsmark area though. This difference is also noticeable in the population statistics. In Misterhult parish, 40% of the jobs are within agriculture, forestry, hunting and fishing, whereas this figure is 0% in Forsmark parish /Miliander et al. 2004ab/.

The amount of lakes and wetlands is considerably greater in the Forsmark area (19% versus 2%).

4.3.2 Edible berries and fungi in the Forsmark and Laxemar-Simpevarp areas

Consumption of berries and fungi are two of several potential pathways for human exposure to radionuclides in the event of a radionuclide release. The potential radionuclide transfer to humans by consumption can be estimated by estimating the yield of berries and fungi /Löfgren et al. 2006/. Berry species that are common in Sweden are above all bilberry (*Vaccinium myrtillus* L), lingonberry (*V. vitis-idaea*), raspberry (*Rubus idaeus* L) /Eriksson et al. 1979/ and rosehip (*Rosa dumalis* Bechst.) /Mossberg et al. 1996/, but also cloudberry (*Rubus chamaemorus* L) and cranberry (*V. oxycoccos* L) /Kardell and Carlsson 1982/. Bilberry, lingonberry and raspberry are common in the whole of Sweden. Raspberry has its highest abundance in the southern parts of the country, while in the north it is sparse to almost non-existent in the northernmost parts. Bilberry and lingonberry, on the other hand, have a higher degree of coverage in the more northern regions and are absent in parts of Skåne in southern Sweden /Eriksson et al. 1979/. Cloudberries and cranberries are two species mainly occurring in peatland areas. Cloudberry can be found all over Sweden except for some small areas in Skåne. Cranberry is rather common from the north to the southern parts of Dalarna, occurring more sporadically further south /Kardell and Carlsson 1982/. Bilberry and lingonberry produce the highest proportion of berries in the northern parts of Sweden /Eriksson et al. 1979, Kardell and Carlsson 1982/. Rosehip is common in grasslands and at the edge of the forest /Mossberg et al. 1996/. Boletuses (*Boletus edulis*, 44%), russulas (*Russula paludosa*, 29%) and northern milk-caps (*Lactarius rufus/trivialis,* 20%) are fungus groups which are commonly found in Swedish forests. The different species of chanterelle (*Cantharellus cibarius*) are the most popular fungi in Sweden, representing c 1.2% of the edible species found. The abundance of edible species differs slightly depending on latitude /Kardell and Eriksson 1987/.

The berry yield may vary between years depending on frost, precipitation, temperature and pollination success /Wallenius 1999/. This variation is even more pronounced among fungi species, where the yield of fruiting bodies may be close to zero certain years followed by years with high yields. This annual variation remains to be explained. Most fungus species are favoured by varied weather with periods of rain followed by periods of warm and dry weather. Many species are sensitive to frost and disappear in early autumn.

Neither berry nor fungus yield has been estimated by direct field surveys in the two areas. An attempt is made below to estimate the yield by using other site-specific information to infer berry production. Bilberry and lingonberry yields are estimated by using a model by /Ihalainen et al. 2003/. As the empirical model was developed for forest planning purposes in Finland, site and growing stock characteristics (fixed predictors) were the most reasonable known factors to use /Ihalainen et al. 2003/. The random part of the model accounts for the effect of plot, measurement year, and cluster /Ihalainen et al. 2003/. According to /Ihalainen and Pukkala 2001/, sites of medium or rather poor fertility produce the highest bilberry yields. The bilberry yield is positively related to tree height, whereas the basal area of spruce and the proportion of deciduous trees are negatively related to the yield. On mineral soils, lingonberry yields are best on poor sites, and it was also found that a high proportion of Scots pine improves the lingonberry yield. The highest yields are found in open areas and in very young stands as well as in sparsely populated stands of large and old trees /Ihalainen and Pukkala 2001/. For other edible berries and fungi, literature values are used to estimate the yield in the two areas.

Method

Bilberry and lingonberry yield

The berry yield has been estimated using the model for *V. myrtillus* and *V. vitis-idaea* by /Ihalainen et al. 2003/. Site-specific soil fertility and tree stand data have been used for the Forsmark and Laxemar-Simpevarp areas in the model. Bilberry yield was predicted using stand age and forest type as fixed predictors in the model. Stand basal area, mean tree diameter and forest type, were used for lingonberry. The yield and carbon content was estimated in fresh weight.

Bilberry

The model describing the bilberry yield is as follows:

$$y_b = \exp(0.0830+0.0103\ t_g + 0.9904\ D_1 + 0.4997\ D_2) \times 2.4507 - 1$$

where

y_b = bilberry yield in fresh weight (kg ha^{-1})

t_g = mean age of trees (year)

D_1 = site dummy: $D_1 = 1$, if the forest site type is medium, and $D_1 = 0$ otherwise

D_2 = site dummy: $D_2 = 1$, if the forest type is rather poor, and $D_2 = 0$ otherwise

Lingonberry

The model describing the lingonberry yield is as follows:

$$y_b = \exp(1.0560 + 0.0005\ D_3\ d_g^2 - 0.1196\sqrt{G}) \times 1.7713 - 1$$

where

y_b = lingonberry yield in fresh weight (kg ha^{-1})

D_3 = site dummy: $D_3 = 1$, if the forest site type is rather poor or poor, and $D_3 = 0$ otherwise

d_g = mean diameter of trees (cm)

G = stand basal area (m^2 ha^{-1})

Classification of soil fertility

In the model by /Ihalainen et al. 2003/, three soils types (fertilities) were used: medium, rather poor and poor. The remaining soil types were grouped into one category, “other”. The soil types were classified by using the vegetation as an indicator of fertility grade /see Ihalainen et al. 2003/. The soil types in the Forsmark and Laxemar-Simpevarp areas were classified by using the field layer vegetation map /Boresjö Bronge and Wester 2003/ over the areas where:

herb-heath type = medium

mesic bilberry heath type = rather poor

dry heath type, and mosaic of dry heath type = poor

and the remaining vegetation types were grouped into the “other” category.

Tree stand data

The characterization of the tree stands for both sites was done on the basis of information from the Swedish National Forest Inventory database /SLU 2007, www/. A regional subset describing woodland was extracted from this database (Table 4-51). The data for the Forsmark area are from the plot inventory performed in 2005, while the data for the Laxemar-Simpevarp area are from the inventory performed in 2004 and 2005.

Table 4-51. Tree stand age, basal area and calibrated basal area diameter for the Forsmark (N= 44) and Laxemar-Simpevarp areas (N= 36) obtained from the Swedish National Forest Inventory /2005, 2004–2005/.

	Site	Mean	Min.	Max.
Tree stand age (yr)	Forsmark	74	22	147
	Laxemar-Simpevarp	61	17	135
Basal area (m^2 ha^{-1})	Forsmark	25	11	48
	Laxemar-Simpevarp	25	9	47
Calibrated basal area diameter (cm)	Forsmark	23	0	37
	Laxemar-Simpevarp	24	9	45

Berry yields for other edible species

The berry yields for other edible species are literature values.

Raspberry

The raspberry yield in Sweden was studied by /Eriksson et al. 1979/ in a three-year study between 1974 and 1977. The raspberry inventory was conducted each year starting in the middle of May or in the beginning of June and lasting until October. The inventory was carried out along transects covering the whole of Sweden, see /Eriksson et al. 1979/ for further details.

Rosehip

The rosehip yield in a five-year period was obtained from inventories conducted at a farm called Ekenäs gård in Södermanland in southern Sweden /Kardell 1993/. All rosehips were collected, without regard to degree of ripeness, in a 5 m^2 circle in 436 locations. The locations were inventoried twice a year in July and September /Kardell 1993/.

Cloudberry and cranberry

The berry yield data used in the report by /Kardell and Carlsson 1982/ were obtained from the Swedish National Forest Inventory 1978–1980 /SLU 2007 www/. In order to estimate the annual Swedish berry yield of cloudberries and cranberries, /Kardell and Carlsson 1982/ used data obtained from the 1,545 subplots distributed over 10 locations in the country. The methodology used by the Swedish National Forest Inventory is described on their webpage /SLU 2007, www/ and the method for estimating the Swedish annual yield of cloudberries and cranberries was found in /Kardell and Carlsson 1982/.

Edible fungi

Edible fungi were defined as those species that, according to /Mossberg et al. 1979/, were edible with or without parboiling before consumption. The mean annual yield of edible fungi was estimated from a five-year period between 1977 and 1981. The fungi were collected in 23 different sampling plots measuring 30×30 or 50×50 metres 5–9 times each year. For further details see /Kardell and Eriksson 1987/.

Carbon content in berries and fungi

Carbon calculations

The carbon content was calculated using the same method as in /Lindborg 2006/, where the carbon in carbohydrates, lipids, and proteins was estimated /Altman and Dittmer 1964, Dyson 1978, Rouwenhorst et al. 1991/.

$$CC_i = 0.53\times Proteins_i + 0.44\times Carbohydrates_i + 0.66\times Lipids_i$$

where,

CC_i is the carbon content in the i-th food type (kg C kg^{-1} fw),

$Proteins_i$ is the protein content in the i-th food type (kg kg^{-1} fw),

$Carbohydrates_i$ is the carbohydrate content in the i-th food type (kg kg^{-1} fw),

$Lipids_i$ is the lipids content in the i-th food type (kg kg^{-1} fw)

The amounts of the different components in berries and fungi were taken from the website of the /National Public Health Institute in Finland 2003–2007/ (Tables 4-52 and 4-54).

The carbon content of berries ranges from 4.2 to 9.3% for the different species (Table 4-53). The carbon content was highest in rosehips, which differ from the other species. If rosehips are excluded, the mean carbon content of berries is 3.3% of the fresh weight.

The carbon content in different species of fungi n fresh weight ranges from 1.4 to 3.3%. The mean value for fungi was 2.1% (Table 4-54). One survey of fungi has been performed in the Forsmark area, where the carbon and nitrogen content was estimated from dry matter (See Section 4.2.5).

Table 4-52. The energy, carbohydrate, lipid and protein content in 100 grams of berry /National Public Health Institute in Finland 2003–2007/.

	Energy content (kJ)	Carbohydrates (g)	Lipids (g)	Proteins (g)
Bilberry	140	6.4	0.6	0.5
Lingonberry	142	6.8	0.5	0.4
Raspberry	142	4.1	0.8	1
Rosehip	392	16	0.5	3.6
Cloudberry	175	7.8	0.5	1.4
Cranberry	92	3.5	0.7	0.4

Table 4-53. The carbon content in different species of berries. Mean carbon content values are calculated with and without rosehip.

	Carbon content in % (fresh weight)
Bilberry	3.5
Lingonberry	3.5
Raspberry	2.9
Rosehip	9.3
Cloudberry	4.5
Cranberry	2.2
Mean (rosehip incl.)	4.3
Mean (rosehip excl.)	3.3

Table 4-54. The energy, carbohydrate, lipid and protein content per 100 grams of fungus /National Public Health Institute in Finland 2003–2007/.

	Energy content (kJ)	Carbohydrates (g)	Lipids (g)	Proteins (g)
Champignon	55	0.3	0.3	2.1
Chantarelle	61	0.4	0.5	1.8
False morel	63	0.5	0.5	1.8
***Boletus* edible**	127	2.9	0.5	3.2
Edible milk-caps	89	2.3	0.5	1.6
Boletus*/*Russula	104	2.9	0.5	1.8

Table 4-55. The carbon content of different species of fungus.

	Carbon content in % (fresh weight)
Champignon	1.4
Chantarelle	1.5
False morel	1.5
Boletus edible	3.3
Edible milk-caps	2.2
Boletus/Russula	2.6
Mean	2.1

The estimated carbon content of berries was lower than previously reported figures /Lindborg and Kautsky 2004, Lindborg 2006/. The method used to estimate the carbon content was the same as in /Lindborg 2006/, but the carbohydrate, lipid and protein contents of the berries differ. In /Lindborg 2006/, the three components for blueberry were found in the Nutrient Database from United States Department of Agriculture /USDA 2004/. However, the American blueberry is a larger species than the European bilberry /Naturhistoriska riksmuseet 1997, www/. This may explain why the carbon content of blueberry is 7% of the fresh weight and only 3.5% in bilberry. The carbon contents of fungi were also somewhat lower than previously reported /Lindborg and Kautsky 2004, Lindborg 2006/. As in the case of berries, it probably has to do with what species were used for the calculations.

The carbon content of different types of food items is often unknown and it is therefore necessary to use some type of estimation/conversion. The carbon content can be estimated based on the composition of the food items, i.e. the amounts of carbohydrates, proteins and lipids. The carbon content differs relatively little in a comparison between the methodology used in /Holland et al. 1991/ and the method described in /Altman and Dittmer 1964, Dyson 1978, Rouwenhorst et al. 1991/. The carbon content of bilberry was c 8% lower when the /Holland et al. 1991/ methodology was used, which is equivalent to 0.27 grams of carbon per 100 grams of bilberry.

Results

Berry yield

The resulting yield estimates are presented in Table 4-56 and Figure 4-40 describes an example of how the total berry yield is distributed in the landscape.

Bilberry

The highest bilberry yield was found in areas with medium soil fertility. The increased tree stand heights positively affect the bilberry yield as well /Ihalainen and Pukkala 2001/. The bilberry yield might therefore be greater in the Forsmark area compared with the Laxemar-Simpevarp area (Table 4-56), since the tree stands were older in Forsmark and thereby might be taller as well. This does not necessarily mean that the bilberry yield for the whole site is higher in the Forsmark area than in the Laxemar-Simpevarp area.

Lingonberry

The lingonberry yield was slightly higher in areas with poor/rather poor soil in Laxemar-Simpevarp, where the calibrated mean tree diameter was somewhat higher (Table 4-56).

Raspberry

The raspberry reaches its maximum yield in areas that have recently been cleared. A cleared area is colonized by raspberries within three vegetative seasons /Kardell 1993/. The coverage of raspberry in young clear-cuts varies between 2 and 4%. As the forest gets older the raspberry yields declines, and after 20–30 years raspberry has totally disappeared /Eriksson et al. 1979/. No co-variance was found between the climate data and the raspberry yield. Nor was there a correlation between good bilberry and lingonberry yield on the one hand and good raspberry yield on the other. The mean raspberry yield was found to be 0.002 gC m^{-2} y^{-1} /Kardell 1993/ (see Table 4-56).

Rosehip

Rosehip is commonly found in grasslands and at the edge of the forest /Mossberg et al. 1996/. The rosehip yield seems to be stable from year to year at approximately 0.062–0.093 gC m^{-2} y^{-1}, with a mean of 0.081 gC m^{-2} y^{-1} grassland /e.g. Kardell 1993/ (see Table 4-56). The estimation of the yield variation was not done due to errors in measurements caused by grazing cows /see Kardell 1993/.

Cloudberry

In Sweden, cloudberries are almost solely found on peatland. The mean yield on peatlands was estimated to be c 0.085 gC m^{-2} y^{-1}, while the mean yield on woodlands was 0.063 gC m^{-2} y^{-1} (see Table 4-56). In calculating the yield per hectare, the mountain areas were excluded /Kardell and Carlsson 1982/. The northern parts of Sweden have the highest cloudberry yields: 46% of the berries are produced in Norra Norrland, 28% in Södra Norrland, 22% in Svealand and 4% in Götaland /Kardell and Carlsson 1982/.

Cranberry

Cranberry was found to grow almost exclusively on peatland. Cranberry is rarely found in dense patches, and trees inhibit cranberry coverage. The mean yield of cranberry on peatland was 0.011 gC m^{-2} y^{-1} and on woodland 0.006 gC m^{-2} y^{-1} (see Table 4-56). As for cloudberry, the yield of cranberries in mountain areas was excluded when estimating the mean yield /Kardell and Carlsson 1982/.

When the Swedish cranberry yield was broken down into four different regions, the areal yield was found to be higher in the southern parts of Sweden for both peatlands and woodlands. The proportion of berries produced was however higher in the northern parts of Sweden (Norra Norrland 41%, Södra Norrland 22%, Svealand 27%, and Götaland 10%) /Kardell and Carlsson 1982/.

Table 4-56. Berry yield (mean, min, max and SD) is presented in gC m^{-2} yr^{-1} for the different species and landscape types. Bilberry and lingonberry mean, min. and max. were calculated using the estimates obtained from the model by /Ihalainen et al. 2003/, where the SD for the Forsmark and Laxemar-Simpevarp areas could not be estimated (see section 4.1). The raspberry mean yields between 1975 and 1977 were used to estimate the min, max and SD /Eriksson et al. 1979/, while the mean yield between 1978 and 1980 was used for cloudberry and cranberry /Kardell and Carlsson 1982/. The rosehip yield was found in /Kardell 1993/, where the mean value was estimated and the min. and max. values were approximated. No estimates of the SD were available from that study.

				gC m^{-2} yr^{-1}			
Species	**Area**	**Landscape type**	**Category**	**Mean**	**Min.**	**Max.**	**SD**
Bilberry	Forsmark	Woodland	Medium	0.050	0.028	0.111	–
	Forsmark	Woodland	Rather poor	0.029	0.016	0.065	–
	Forsmark	Woodland	Otherwise	0.016	0.008	0.039	–
	Laxemar-Simpevarp	Woodland	Medium	0.043	0.026	0.097	–
	Laxemar-Simpevarp	Woodland	Rather poor	0.025	0.015	0.058	–
	Laxemar-Simpevarp	Woodland	Other	0.006	0.009	0.004	–
Lingonberry	Forsmark	Woodland	Rather poor/ Poor	0.009	0.008	0.012	–
	Forsmark	Woodland	Other	0.006	0.008	0.004	–
	Laxemar-Simpevarp	Woodland	Rather poor/ Poor	0.009	0.009	0.018	–
	Laxemar-Simpevarp	Woodland	Other	0.006	0.009	0.004	–
Raspberry	Sweden	Woodland	–	0.002	0.002	0.002	0.000
Rosehip	Sweden	Pastureland	–	0.081	0.062	0.093	–
Cloudberry	South of the Norrland border	Peatland	–	0.085	0.063	0.096	0.019
	South of the Norrland border	Woodland	–	0.063	0.046	0.079	0.017
Cranberry	South of the Norrland border	Peatland	–	0.011	0.007	0.013	0.003
	South of the Norrland border	Woodland	–	0.006	0.005	0.007	0.001

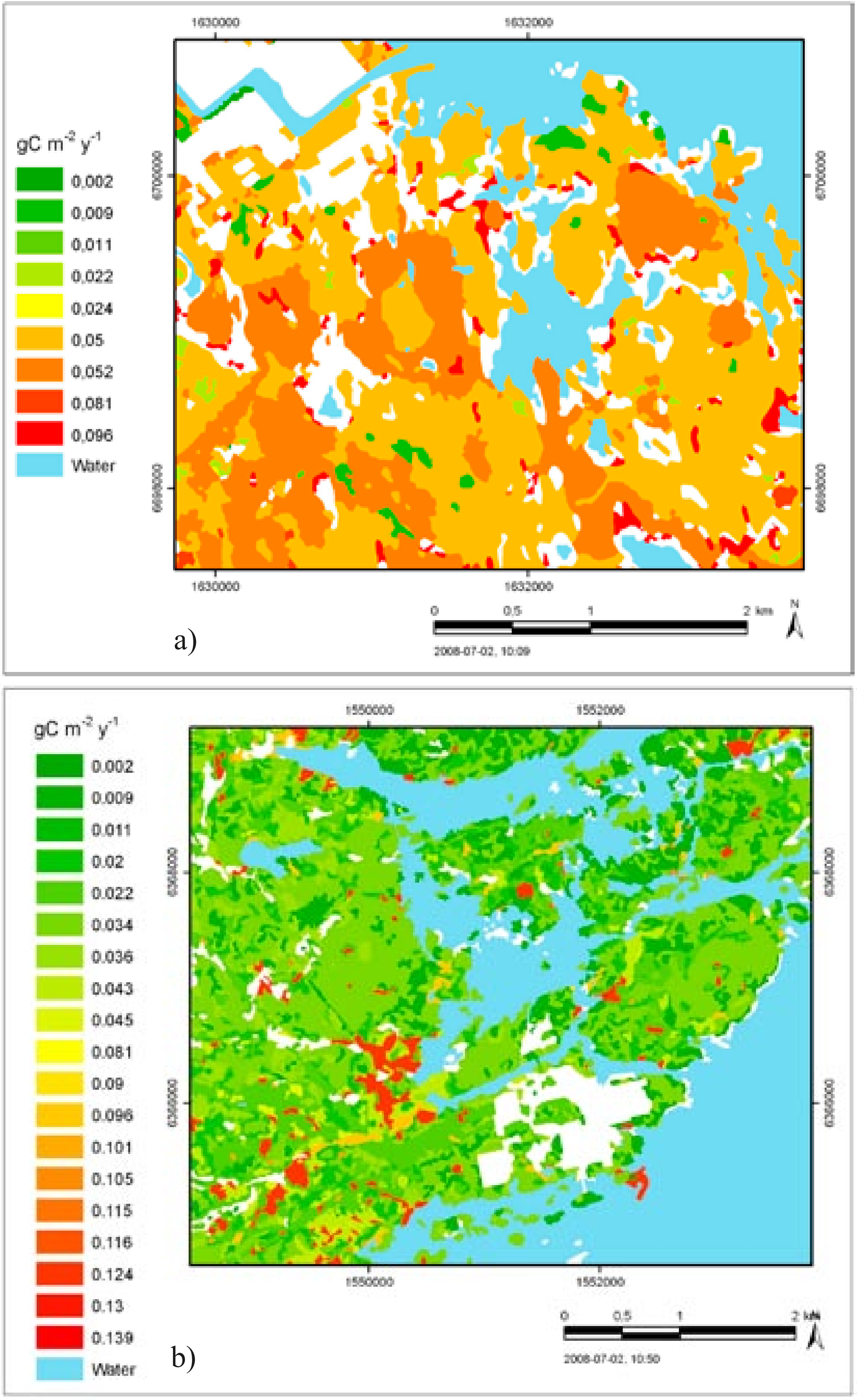


Figure 4-40. *Total berry yield from different species. The maps show a subset of the total area covered by the spatial models in a) Forsmark b) Laxemar-Simpevarp.*

Edible fungus yield

The mean yield of fungal fruiting bodies between 1977 and 1981 was found to be 0.091 gC m^{-2} y^{-1} for the whole of Sweden (Table 4-57). If the northernmost part of Sweden (north of the Limes Norrlandicus) is distinguished from the rest of Sweden, the annual yield for southern Sweden increases to 0.122 gC m^{-2} y^{-1}. The annual yield in the northern part of Sweden was estimated to be approximately 30% lower than in the southern part although the difference was not significant. The annual yield of the most popular species, i.e. the different species of chantarelle (*C. cibarius* and *C. tubaeformis*) and edible boletuses (*B. luteus* and *B. edulis*), was 0.003 gC m^{-2} y^{-1}, which represents barely 5% of the edible fungi /Kardell and Eriksson 1987/.

Discussion

Berry yield

Berry yield studies are generally rather small, local investigations typically consisting of only a few study plots, probably due to the laborious work involved in picking and measuring berry yields over large areas and for longer time periods /Wallenius 1999/.

The model used for estimating the berry yield for bilberry and lingonberry in the Forsmark and Laxemar-Simpevarp areas was based on a study performed in North Karelia. Forsmark (c. 60˚) and Karelia (63–64˚) are closer to each other in latitude than Laxemar-Simpevarp (c. 57˚) and Karelia. This could mean that the estimated results reflect the Forsmark area better than the Laxemar-Simpevarp area. However, the model provides results similar to other studies performed in Sweden and Finland (Table 4-56). Most models used to predict berry yield do not consider actual conditions on the sites, which this model does. By utilizing the site-specific soil fertility and tree stand data, the model takes site characteristics into account. By means of this approach it was also possible to distinguish more or less productive areas.

In the study by /Ihalainen et al. 2003/, there is variation caused by a random part (effect of plot, measurement year and cluster) and a fixed part (site and growing stock characteristics) of the model. The fixed part of the model explains 6% of the total variance in the back-transformed bilberry yield ($R^2=0.06$) (RMSE), which is 0.077 gC m^{-2} y^{-1}. A major part of the residual variation (58%) was caused by the random sample plot effect. Within-sample-plot and within-year variation accounted for almost 40% of the variation, while the proportion explained by the year effect was only a few percentage points. In the lingonberry model, 3% of the variation is explained by the fixed part ($R^2=0.03$), which is 0.028 gC m^{-2} y^{-1}. The effect of the random components, except the year, was statistically significant. This suggests that, in a given year the level of lingonberry yields varied from cluster to cluster. In addition, variation occurred in lingonberry crops between different sample plots. Almost one-third of the variation consisted of random error. The variance in the random sample plot effect accounted for half of the total variance in the random effects. The proportions of year × cluster and year were 9% and 10%, respectively.

As shown in the study by /Kardell 1993/, the heterogeneity of the land greatly influences the berry yields (Table 4-59). This variation should be kept in mind when trying to predict the berry yield in an area.

Table 4-57. The mean, min, max and SD of edible fungi in Sweden in gC m^{-2} yr^{-1} based on the annual mean yield between 1977 and 1981 /Kardell and Eriksson 1987/.

			gC m^{-2} yr^{-1}			
Species	**Site**	**Landscape type**	**Mean**	**Min.**	**Max.**	**SD**
Edible fungi	Sweden	Coniferous forest	0.091	0.063	0.122	0.028

Table 4-58. Estimated mean yield for the three different soil fertilities (gC m^{-2} yr^{-1}) of bilberry and lingonberry in the Forsmark and Laxemar-Simpevarp area compared with results from field studies performed in Sweden and Finland.

Site	Reference	(gC m^{-2} yr^{-1}) Mean yield of bilberry	Mean yield of lingonberry
Sweden	Kardell 1980	0.031	0.019
Sweden (Ekenäs farm)	Kardell 1993	0.030	0.014
Finland	Ihalainen et al. 2003	0.046	0.011
Sweden (Forsmark)	Ihalainen et al. 2003	0.032	0.008
Sweden (Laxemar-Simpevarp)	Ihalainen et al. 2003	0.028	0.008

Table 4-59. Mean yield of berries on different landscape types at Ekenäs between 1981 and 1985 in gC fresh weight m^{-2} yr^{-1} /Kardell 1993/.

Landscape type	Bilberry	Lingonberry Fresh weight gC m^{-2} yr^{-1}	Raspberry	Rosehip
Woodland				
-bare land	0.009	0.007	0.169	–
-young forest	0.009	0.059	0.023	0.013
-"thinning" forest	0.005	0.059	0.002	0.001
-older forest	0.085	0.000	0.000	–
Rock/waste land	0.012	0.001	0.000	–
Wetland	0.010	0.005	–	–
Pasture	–	–	0.011	0.076

Edible fungi yield

Fungal fruiting body production at the Ekenäs farm was estimated to be 0.042 gC m^{-2} y^{-1} (Table 4-60), which is considered to be a low figure. This could be explained by the character of the farm area, which was in general quite dry and consists primarily of rock/waste land /Kardell 1993/. Since the Ekenäs farm is not representative of the Forsmark and Laxemar-Simpevarp areas in terms of land characteristics, it can be assumed that fruiting body production is higher in the Forsmark and Laxemar-Simpevarp areas. The fungal fruiting body production estimates from the Swedish inventories between 1977 and 1981 are probably more representative when it comes to estimating the fungal yield in the two areas (0.090 gC m^{-2} y^{-1} for the whole of Sweden), but the estimated yield for the southern part of Sweden (below the Norrland border) should be even more appropriate (0.122 gC m^{-2} y^{-1}). The annual minimum yield of edible fungi in Finland was reported to be between 0.042 and 0.210 gC m^{-2} y^{-1}, where the variation was caused by the woodland type (/Rautavaara 1947/ in /Kardell and Eriksson 1987/). /Kardell and Eriksson 1987/ argue that the larger amount of edible fungi in Finland has to do with cultural differences. The people in Finland have been gathering fungi as a resource for a much longer time and are therefore able to find a larger quantity of edible species. The reported figures for edible fungi in Finland were in general higher than in Sweden. However, the yield in the northern parts of Finland was found to be considerably lower than in the south /Kardell and Eriksson 1987/. This suggests that the figure estimated for southern Sweden should be used to estimate the yield in the two areas instead of the total yield for the whole of Sweden. Furthermore, / Kardell and Eriksson 1987/ estimated that the collected amount of fungus represented approximately 70–80% of the total annual yield.

Table 4-60. Mean yield of edible fungi in gC m^{-2} yr^{-1} from three different field studies performed in Sweden and Finland.

Site	Time period	Landscape type	Fungal yield (gC m^{-2} yr^{-1})
Ekenäs*	1981–1985	Deciduous forest	0.042
Sweden**	1977–1981	Coniferous forest	0.090
Finland***	1944–1946	Coniferous forest	0.042
			0.210

*Kardell 1993.
**Kardell and Eriksson 1987.
***Rautavaara in Kardell 1993.

4.3.3 Game hunting

Introduction

The species that are mainly hunted for human consumption are moose, roe deer and hare. Hunting data for moose were obtained from the County administrative boards (*Sw: Länsstyrelserna*) covering five years (1999–2003), while hunting data for roe deer and hare were obtained from the National Association of Huntsmen (*Sw: Svenska Jägareförbundet*), also covering five years (1997–2001). The data were compiled, processed and analyzed in /Miliander et al. 2004ab/. The data from the County administrative board are reported for the parish as well as for the municipality and the County. The data from the National Association of Huntsmen are reported for the local hunting zone (Oskarshamns Norra jaktvårdskrets in Oskarshamn and Östhammars jaktvårdskrets in Forsmark).

The average harvest of moose in the parish and the average harvest of roe deer and hare in the local hunting zone reported in /Miliander et al. 2004ab/ are applied to the Forsmark area and the Laxemar-Simpevarp area (Table 4-61 and 4-62).

The Forsmark area

According to the figures from the County Administrative Board in Uppsala, moose hunting is more extensive in Forsmark parish than in the municipality and county as a whole. The harvest has on average been greater in Forsmark parish than in Östhammar Municipality and Uppsala County during the entire dataset period (1997–2003). The number of harvested moose per km^2 reached a peak in 2000–2001. The number per km^2 decreased in 2002 and 2003.

Table 4-61. The harvest of free-living mammals in the Forsmark area, Östhammar Municipality and Uppsala County.

Game-hunting	Forsmark		Östhammar Municipality		Uppsala County	
	mean (ind·km^{-2})	SD	mean (ind·km^{-2})	SD	mean (ind·km^{-2})	SD
Moose[1]	0.53	0.08	0.42	0.05	0.39	0.04
Roe deer[2]	1.91	0.53				
European hare[2]	0.28	0.13				
Mountaine hare[2]	0.13	0.15				

[1] Statistics from The Administrative Board of Uppsala County for 1999–2003.
[2] Statistics from The National Association of Huntsmen (1997–2001), reported for the local hunting zone (Östhammars jaktvårdskrets).

Table 4-62. The harvest of free-living mammals in the Laxemar-Simpevarp area, Oskarshamn Municipality and Kalmar County.

Game-hunting	Laxemar-Simpevarp		Oskarshamn Municipality		Kalmar County	
	mean (ind·km^{-2})	SD	mean (ind·km^{-2})	SD	mean (ind·km^{-2})	SD
Moose[1]	0.49	0.10	0.43	0.10	0.29	0.05
Roe deer[2]	2.15	0.99				
European hare[2]	0.29	0.11				
Mountaine hare[2]	0.10	0.07				

[1] Statistics from The Administrative Board of Kalmar County for 1997–2003.

[2] Statistics from The National Association of Huntsmen (1997–2001), reported for the local hunting zone (Oskarshamns Norra jaktvårdskrets).

The Laxemar-Simpevarp area

According to the figures from the County Administrative Board in Kalmar County, moose hunting is more extensive in Misterhult parish than in the municipality and the county as a whole. The harvest has been greater in Misterhult parish than in Oskarshamn Municipality and Kalmar County during the entire dataset period (1997–2003). The number of harvested moose per km^2 reached a peak in 2000.

Discussion

The moose harvest is somewhat greater in Forsmark parish than in the Laxemar-Laxemar-Simpevarp area (Misterhult parish). The discrepancy is very small, however (on average 0.53 moose·km^{-2} compared with 0.49), and it is not possible to draw any definite conclusions from the figures. The resemblance in hunting statistics is matched by the similarity in the density figures (1.0 moose·km^{-2} in the Forsmark area and 1.07 in the Laxemar-Simpevarp).

Hunting of roe deer is also very similar at the two sites, even though the population density is greater in the Forsmark area. The average harvest of European hare and mountain hare has also been similar in the Forsmark area and Laxemar-Simpevarp during the time period. However, the population of European hare, which inhabits fields, predominates in the Laxemar-Simpevarp area, whereas the forest species, mountain hare, is somewhat more frequent in the Forsmark area.

4.3.4 Recreation

The Forsmark area

The recreational value of the Forsmark area lies in its pristine nature with a wilderness character /Ottosson 2006b/. There is also a rich fauna of birds and game animals, which attracts bird watchers and hunters from far away.

During the period 2002–2007, Östhammar Municipality cooperated with other municipalities in Roslagen, Sweden and in Finland and Åland in a project called the Archipelago Route (*Sw: Skärgårdsleden*), aimed at marketing the recreational activities available in the area and developing tourism in a sustainable way /Ottosson 2006b/. The companies involved in the Archipelago Route can offer packages or single activities such as horseback riding, canoeing and biking. The Archipelago Route is promoted via the website *www.archipelagoroute.com*.

Aside from the Archipelago Route project, the municipality has no plans to expand recreational activities in the area around Forsmark /Ottosson 2006b/.

The Laxemar-Simpevarp area

There are primarily three areas that are used for recreation in the Laxemar-Simpevarp area /Ottosson 2006a/. These are Ostkustleden (the East Coast Trail), Kråkelund and Hamnefjärden, areas that are frequently used by both tourists and local inhabitants. A hike along Ostkustleden goes through forests and pastures and it is possible to sunbathe, fish and pick berries along the trail. Kråkelund, approx. 5 km northeast of the Oskarshamn nuclear power plant, attracts many bird watchers, but it is also a popular place for scuba divers. Hamnefjärden is a unique marine area since the water temperature can be up to ten degrees above the normal temperature due to the cooling water outlet. The water temperature attracts canoeists all year round and sunbathers until late autumn.

4.3.5 Confidence and uncertainties

Potential edible berry and fungus yield

The yield of berries has been estimated in some studies, but few have been able to relate these estimates to factors varying within a region. The regression approach using a number of forestry parameters has resulted in spatial descriptions of the lingonberry and bilberry yield within the sites that are close to the results of other studies.

In general, there are no long-term studies available that can be used to estimate the potential variation. Studies presented suggest a surprisingly low variation. The variation in yield is expected to be large, especially for fungi, due to large annual variation in e.g. precipitation. In a safety assessment, it is the long-term average that would be most appropriate to use, and in this sense there is nothing that suggests that the studies were made during years that would be considered extreme in any direction. However, another factor that may vary is the actual collection by humans. The cultural differences that have been used to explain a part of the difference in yield figures of edible fungi in Sweden and Finland is one example of that (in Finland more species are considered to be edible).

Wild-life hunting

For all four animals important for wildlife hunting (moose, roe dear, European and mountain hare) the hunting pressure is similar between the sites. During the rather short time period that the statistics were built upon (seven years for moose and five years for the others), the standard deviation was rather small, except for roe deer that also showed the largest populations at both sites. The large roe deer populations are expected to be sensitive to severe winters, which may explain a part of the large variation. Generally, there is a high hunting pressure and especially on moose /Cederlund 2008, Cederlund et al. 2004/. A much higher hunting pressure would probably not be sustainable. Recently, predators, such as lynx and red fox, have become more abundant and expanded their distribution, which imply negative affects on their prey populations and ultimately also on the wild-life hunting.

Recreation

Recreation covers a large number of potential activities and the overall extent of such activities have generally increased during the years. Sporadic or spontaneous activities are difficult to predict, and as long as no specific facilities aiming at recreation are planned, it is assumed that the recreation will continue to be sporadic.

5 A conceptual ecosystem model

This chapter contains a general description of processes important for transport and accumulation of elements in the terrestrial ecosystem. A conceptual ecosystem box model describes the biota, the physical environmental conditions and the transfer of matter or energy between these as well as interactions with water, solid matter (minerals), solutes and organic matter. The model is used in the following chapters to describe the fluxes and accumulation of carbon, a proxy for organic matter. This conceptual approach will also be an important input to the radionuclide models that will describe the fluxes and accumulation of radionuclides in different ecosystems.

Pools and fluxes of organic matter in ecosystems are of increasing interest to Environmental Impact Assessments, owing to their potential to describe and predict flow and accumulation of bioavailable contaminants, e.g. radionuclides, in a landscape context /Naito et al. 2002, Carrer et al. 2000/. The chemical behaviour of many bioavailable contaminants and radionuclides is similar to that of other elements, such as macronutrients or trace elements /Whicker and Schultz 1982, Sterner and Elser 2002/ and these analogues may thus be utilized for modelling purposes. Similarly, there are elements that passively assimilated by plants and may therefore be better described by water flow through the plant, e.g. transpiration /Greger 2004/. However, in general, a multitude of bioavailable radionuclides with various behaviours assimilated into living tissue will ultimately follow the path of organic matter in the food web. A comprehensive descriptive ecosystem model, describing pools and fluxes of organic matter, may therefore be useful in describing and quantify the accumulation and transfer of radionuclides in general. Consequently, production of organic material, or net primary production (NPP), may serve as an upper limit to the incorporation of different elements in primary producers /Kumblad et al. 2006/. Fluxes to other trophic levels than vegetation, e.g. large herbivores, predators and humans, may be used to evaluate the potential exposure of these consumers from food intake.

Apart from the immediate transfer of elements via organic matter further up in the food chains, elements may also be accumulated or immobilized in the soil, either as ions (not incorporated into living tissue) or in organic material from litter production. Decomposition of organic matter originating from the vegetation leads to a release of elements into the upper part of the soil profile. Accumulation in the soil can be described by adsorption to mineral particles or organic material or by active discrimination of elements by plant roots. Such processes are important to describe in order to evaluate the potential of different elements to accumulate in the soil.

The specific configuration of an ecosystem model is determined by its purpose, e.g. to describe the emission of carbon to the atmosphere, and the spatial scale it will be used on, e.g. fluxes within a specific ecosystem or on the landscape level. Historically, this approach has been used since the 1950s in order to quantify pools and fluxes of organic matter e.g. /Odum and Odum 1955/. The approach emphasizes the general properties of the ecosystem without documenting all the underlying mechanisms and interactions. The resulting model may provide a mechanistic understanding of how matter or energy is distributed and how it flows, as well as important suggestions on how these pools and fluxes are regulated. In order to build an ecosystem model the ecosystem must be divided into different functional components, which are connected to each other by fluxes of matter. This approach requires information on the biota, e.g. food webs, and abiotic conditions, e.g. soil descriptions, which makes it possible to describe the functional groups or compartments in the model. Moreover, a number of properties describing pools and fluxes of matter or energy have to be known or quantified by field measurements.

In brief, this chapter presents a conceptual model aimed at:

- Providing an understanding of pools and fluxes of carbon (used as a proxy or analogue for organic matter) in terrestrial environments. This knowledge underpins the fine- (Chapter 6) and coarse-resolution (Chapter 7, 8) descriptive ecosystem models describing pools and fluxes of organic matter in the terrestrial landscape of Forsmark and Laxemar-Simpevarp.
- Providing a basis for mass balance calculations of a large number of elements and isotopes (radionuclides) on the scale of the discharge areas (Chapter 9).
- Providing a basis for a conceptual understanding of transport and accumulation of other elements and thereby underpinning the radionuclide models describing radionuclide transfer and accumulation processes in terrestrial ecosystems at the site (e.g. Chapter 10).

5.1 Pools and fluxes in the conceptual ecosystem model

A conceptual ecosystem model for terrestrial systems was derived based on generic knowledge of important ecosystem processes and site-specific knowledge of the vegetation (Chapter 4), soil (Chapter 3 and 4 /Sohlenius and Hedenström 2008, Hedenström and Sohlenius 2008/) and food webs (Section 4.2). A comprehensive description of the pools and fluxes follows below, see Figure 5-1. The rationale for including, excluding or merging certain pools and fluxes is also discussed. Another aim is also to briefly describe internal processes within boxes that are of importance to element transport and accumulation in general. Some fluxes such as gas emission are not represented in Figure 5-1 (e.g. NH_3, N_2 or N_xO_x) but will be discussed in the section describing heterotrophic soil respiration. As a rule, the conceptual model should be applicable to all the different ecosystems included in the terrestrial system. The wetland ecosystem differs in mainly two respects: it periodically has a high groundwater table and it receives runoff from the surrounding catchment, but all the pools and fluxes in figure 5-1 should be applicable (see also Section 4.1.1).

5.1.1 Primary producers

The biomass in the terrestrial environment is strongly dominated by primary producers. The primary producers were divided into three functional groups: tree, field and bottom layers (Figure 5-1), based on differences in turnover and water and nutrient uptake (e.g. bryophytes lacks roots). The tree and field layers were further subdivided into above-ground green biomass and woody biomass, comprising both above and below-ground coarse roots and fine root biomass, and corresponding to different allocation and turnover time patterns. The green tissue and fine roots are continuously replaced while the dead tissue, e.g. wood, will remain until the death of the entire tree. Trees are, when present, often the major component of the total biomass. The field layer consists of herbs, grasses and dwarf shrubs (e.g. *Vaccinium vitis-idaea*). The significance of this layer in relation to the total plant biomass varies between habitats, from being the major constituent in grassland to being of low importance in some types of wetlands and forests. The bottom layer includes all plants that are directly attached to the ground or litter, such as lichens and mosses. Lichens may be the dominant plant in dry Scots pine forests, while mosses may be of significance in moist Norway spruce forests and comprise the dominant plant group in mires.

Roots are often defined according to their function, where fine roots have the major function of absorbing water and nutrients from the surrounding soil, and coarse roots may have multiple functions, such as absorbing water and supporting the above-ground plant, with size often determining function /Persson, 2002/. There is no conventional definition of fine roots, but many studies of forest biomass have defined fine roots as having a diameter less than 1–2 mm /Vogt and Persson 1991, Persson and Stadenberg 2007b/ and coarse roots having a diameter of more than 5 cm. In this report, fine roots are defined as <2 mm (see also Chapter 6). However, this distinction is more or less arbitrary and is crudely related to their function (see Section 4.1.3).

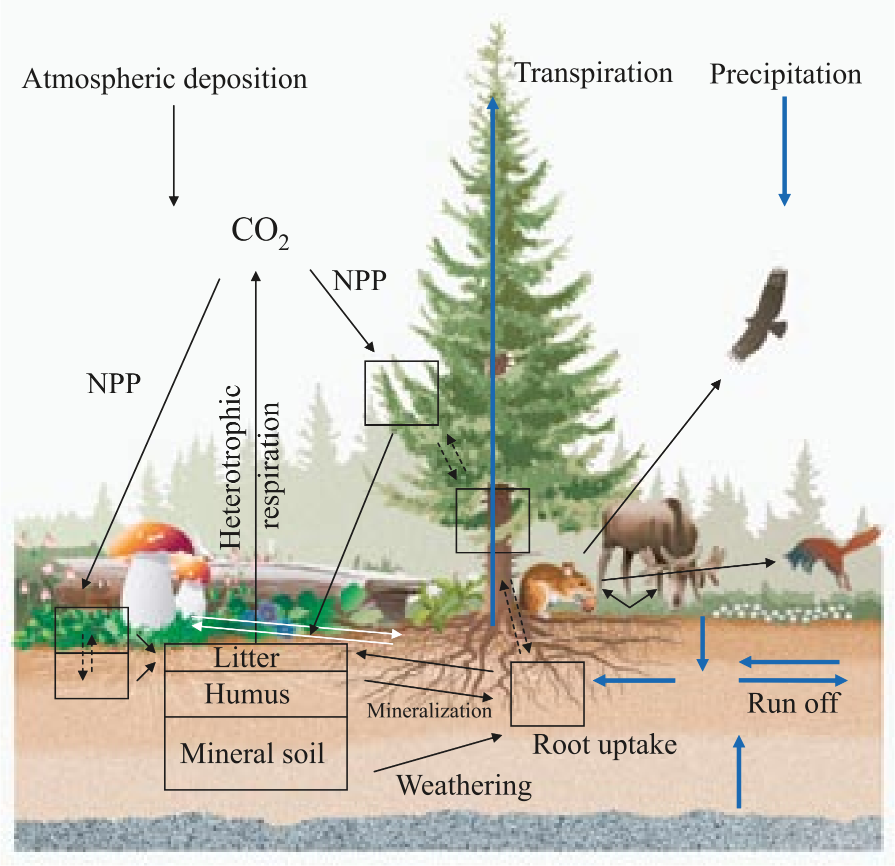


__Figure 5-1.__ A conceptual terrestrial ecosystem model, where black boxes symbolize pools of carbon/organic matter/element, arrows symbolize carbon/organic matter/element fluxes and blue arrows symbolize water fluxes. The white arrows symbolize the mutualistic relationship between plants and ectomycorrhizal fungi. Broken arrows denote internal fluxes within plants.

Primary production

Photosynthesis provides the carbon and the energy that are essential for many important processes in the ecosystems. Photosynthesis directly supports plant growth and produces organic matter that is consumed by animals, humans and soil microbes. The photosynthesis at an ecosystem level is termed gross primary production (GPP). Approximately half of the GPP is respired by plants to provide the energy that supports the growth and maintenance of biomass /Chapin et al. 2002/. The net carbon gain is termed net primary production (NPP) and is the difference between GPP and plant respiration Figure 5-1. NPP is allocated among different plant functional components such as leaves, fine roots, stem and reproductive tissue, all with different biomass turnover times. NPP is regarded here as the sum of all materials that have been produced and are retained by live plants at the end of an interval and the amount of organic matter that was both produced and lost by the plants during the same interval /Clark et al. 2001/. NPP is restricted by light and the uptake of water, macro- and micronutrients from the soil.

Transpiration

An upward flow of water is driven by a combination of evaporation from the leaf/needle surface and transpiration from the vegetation. This is a passive process linking the water around roots with the water in the plants and the water in the atmosphere /Larcher 1995/. This process may be of importance for the upward transport of substances in the soil due to hydraulic lift /Caldwell et al. 1998/, but it is even more important for the active or passive transport of elements or substances dissolved in water into and in the plant. It is, however, of minor importance for transport of e.g. DOC.

Root uptake of mineral nutrients

Root uptake is a balance between demand by the vegetation and supply in the soil. Vegetation demand is determined by growth, and when nutrients are present in smaller amounts than required, growth is limited according to the Liebig's law of the minimum. Consequently, the plants preferentially invest most in absorption of the nutrient that most strongly limits growth /Chapin et al. 2002/. Roots may take nutrients from the soil in the following three ways: absorption of nutrient ions from the soil solution, exchange absorption of adsorbed nutrient ions by releasing H+, and mobilization of chemically bound nutrients by releasing organic compounds capable of forming soluble complexes with nutrients /Larcher 1995/. Nutrients in the soil solution are available to roots by diffusion and the mass flow of soil water to roots caused by the transpirational water loss by plants (see above). Nutrients are also made available by root activity, e.g. growth.

Translocation and retranslocation of mineral nutrients within plants

Mineral nutrients are rapidly translocated via the xylem, by the transpiration stream from the root to the shoot. The retranslocation of mineral substances incorporated into plant substances is mediated by the phloem, and there may be great variation in how easily they are redistributed /Larcher 1995/. Nutrients such as N, P and S have high concentrations in young leaves and are gradually moved with the ageing of the leaf. Heavy metals and alkaline earths, especially Ca, accumulate steadily in the leaves (the end of the xylem translocation route) /Greger 2004, Larcher 1995/.

Additional fluxes

There are a number of fluxes that may be considered less important in comparison with the size of the other internal ecosystem fluxes and could therefore be omitted. Studies concerning volatile and leachable components above ground suggest that these components constitute an insignificant loss of the forest NPP /Clark et al. 2001, Persson and Nilsson (ed.) 2001/. Root exudation is the secretion of soluble organic compounds by roots into the soil. No estimates of root exudates are known at the forest stand level, and this flux is therefore left for further investigation. Ingrowth, which describes the continuous recruitment of new trees, has been disregarded because ingrowth is expected to have a low impact on the biomass and NPP estimations in managed forests. Roots may take up CO_2 in small amounts, but this is considered to be of less importance than the amount that is assimilated through the needles/leaves.

5.1.2 Consumers

The consumers may be divided in at least three functional groups: secondary producers, tertiary producers and humans. Furthermore, the secondary producers are divided into herbivores and mycorrhiza forming fungi. Terrestrial consumers normally consume a relatively small proportion of net primary production (NPP). /Cyr and Pace 1993/ conducted a review of 67 terrestrial ecosystem studies and concluded that the median removal of NPP by herbivores was 18% of the NPP. This flow of matter through individuals in the food web makes potential accumulation of substances incorporated into vegetation plausible. More productive ecosystems support higher levels of absolute consumption by herbivores and therefore maintain higher herbivore densities /Cyr and Pace 1993, Griffin et al. 1998/. This suggests that herbivory is dependent on the size of NPP. In general, the quantification of fluxes in the food web is based on the energy demand (field metabolic ratio) of the specific functional groups calculated from their density and body weight. The ability of functional group to assimilate the energy in their diet is discussed in Section 4.2.

Secondary producers I (herbivores)

Consumers in terrestrial environments, such as herbivores, are often of minor importance with regard to biomass, and their effects on the vegetation may be restricted to certain vegetation types, such as grasslands. Above-ground vertebrate herbivory, such as browsing, is easier to quantify, while invertebrate herbivory and specifically below-ground herbivory may generally be more difficult to estimate. A review of invertebrate herbivory showed that herbivores generally consume less than 10% of NPP in forests, except during insect outbreaks when their consumption can be up to 50% of NPP /Schowalter et al. 1986/. Herbivory by insects on Scots Pine (Pinus sylvestris) was estimated to be 0.7% of the total needle biomass and 2.5% of the total needle production during one year /Larsson and Tenow 1980/, while root consumption by phytophagous nematodes was estimated to be 0.3% of the annual production of fine roots /Magnusson and Sohlenius 1980/. In general, herbivory is excluded from the calculations of NPP, due to its low documented average impact on total NPP in boreal systems.

Secondary producers II (fungi)

Mycorrhiza is a symbiotic relationship between plant roots and fungal hyphae. The plant acquires nutrients, mainly nitrogen and phosphorus, from the mycorrhiza, and in return the fungus obtains carbohydrates, which is the major carbon source for these fungi. Carbon transfer from vegetation through roots to fungi is of significant importance when describing the flow of carbon /Fitter et al. 2000/. There are two main types of mycorrhizas: arbuscular mycorrhizas (AM) and ectomycorrhizas (EM). A third type, the ericoid mycorrhiza, is exclusively formed by plants of the order Ericales. In boreal forests and some temperate forests and in heathland ecosystems, EM associations dominate the root system of most plant species /Fitter et al. 2000, Read 1994/. Some studies indicate that the loss may be significant at the individual level, with up to 30% of NPP drained to the mycorrhizas /Chapin 2002/. The fine roots of forest trees are almost always infected by mycorrhizal fungi /Persson 2002/. Their contribution to the total biomass is low (≈ 1% /Vogt et al. 1982/) and is often included in the quantification of fine root biomass or turnover /but see Vogt et al. 1982/ because they are attached to the fine roots. Saprophytic fungi, which grow on dead organic material, are considered to be part of the soil community that, together with soil fauna and microbes, drives the heterotrophic soil respiration and are not considered separately.

Tertiary producers (carnivores and insectivores)

This group represents the predators above herbivores in the food web. They include carnivores and insectivores. Carnivores are mainly top predators such as mammals, e.g. lynx, or birds, e.g. sea eagle. Insectivores, which mainly include birds and amphibians, are often themselves part of the diet of carnivores.

Humans

Commercial forestry is the main factor structuring forests in southern Sweden (see Section 4.1). However, the impact of human management on different vegetation types is not conceptualized as such in the model. It will rather be a consequence of which vegetation type it is applied to and how the vegetation type is parameterized.

Humans may utilize a number of resources in the landscape, such as crops, wild game, berries and fungi. Human consumption may either be quantified by estimating current consumption or be estimated as potential consumption, i.e. lingonberry production. The problem with describing actual consumption today is that it may vary over time. For example, utilization of berries and fungi was more intense in the past, whereas an estimate of the potential (maximum) consumption of e.g. lingonberry will set the upper limit on what is possible to consume. Traditionally, humans have created different types of land cover for food production. Land areas for haymaking and browsing were an important resource for supporting livestock. Such areas, including meadows (more or less wet, which were later transferred to arable land) and semi-natural grasslands, are today rare compared with their historical distribution.

5.1.3 Soil

The soil contains macro- and micronutrients, and water, which are important predictors for plant production /Larcher 1995/. Bulk density, hydraulic conductivity and field capacity are predictors for availability and/or presence of these predictors, as well as for elements in general. In boreal and hemiboreal forests the soil contains the largest pool of carbon and nitrogen /e.g. Chapin 2002/. Most of the organic matter produced in the ecosystem enters this pool, where it is decomposed into inorganic nutrients, recalcitrant products and carbon dioxide.

Soil compartments

In a typical boreal forest the soil can be divided into the litter pool, the humus pool and the mineral soil pool. The litter pool, consisting of shed plant parts and fine and coarse woody debris such as standing dead trees and logs, is continuously being renewed due to incoming fluxes from the vegetation and outgoing fluxes in the form of decomposition (CO_2) and formation of less easily degradable fractions accumulated in the humus pool. The litter pool has the shortest turnover time of the three pools. The pool of coarse woody debris, which is a part of the litter pool, has a considerably longer turnover time, but is generally small in most well-managed forests today.

The humus layer, which consists of more or less decomposed organic and recalcitrant matter, constitutes a significant part of the soil organic matter (SOM) in some vegetation types such as mires. Peat is the most extreme soil type, where little of the organic matter has been mineralized due to the anaerobic environment induced by a near-surface water table. Peat-forming wetlands are carbon sinks and a thick organic layer might be accumulated over time. A measure of the organic matter content of the humus layer is its thickness, and this layer may accumulate considerable amounts of carbon over time /Olsson et al. 2008/. High organic matter contents in the mineral soil layer are often an indication of well-drained nutrient rich soils. These soil types often have a less distinct boundary between the humus and mineral soil layers. This is partly an effect of increased bioturbation, which is the movement of matter in the soil caused by soil fauna such as earthworms that occurs at great depths in well-drained and well-buffered soils /Persson et al. 2007/.

Most carbon mineralization occurs close to the surface and involves a wide array of different decomposers. They are small and numerous, and constitute a small but active part of the carbon pool in the soil. Saprophytic fungi are important decomposers but are mainly considered in the earlier part of the decomposition stage, e.g. litter, logs and branches. Another fraction of the soil organic matter is transported further down in the soil, either by bioturbation or by water movement (percolation). The dissolved organic carbon (DOC) is transported downward in the soil profile and becomes less mobile in lower soil horizons due to soil sorption processes /Neff and Ashner 2001, Berggren et al. 2003/. This fraction probably contains a substantial fraction of the carbon that is retained over time in woodland soils and is often referred to as the slow decomposing carbon pool, consisting of humins and humic acids /Schlesinger 1997/. Generally, the mineral soil has the largest carbon pool in a boreal forest /Olsson et al. 2008/.

Organic matter with assimilated radionuclides that is turned into litter would quickly be decomposed, creating an excess of radionuclides in comparison with carbon in the humus and upper mineral soil layer. The fate of these radionuclides would depend on the strength of their chemical interaction with the solid phases of the different soil horizons /Tipping 1996/. The resulting leaching or retention of radionuclides in soil can be further described as a function of precipitation, evapotranspiration and sorption in soil /Baes and Sharp 1983/.

Rhizosphere

Root uptake alters the chemical conditions around the roots, the rhizosphere, by reducing nutrient concentrations and by altering the pH due to an excretion of H+. The lowered pH also increases the accumulation of cations (see under section headed "Root uptake of mineral nutrients"). Moreover, carbon enters the rhizosphere both as fine root turnover and as labile carbon exudation from the fine roots. This carbon stimulates the growth of bacteria and can increase nutrient mineralization.

Weathering

Apart from the recirculation of mineral nutrients entering the soil from litter production (see below), mineral nutrients also enter the soil from a continuous weathering of the parent rock or soil material /Chapin et al. 2002, Sohlenius and Hedenström 2007/. This weathering is promoted by warm and wet conditions, but also by biological activity, and is particularly high in the rhizosphere /Chapin et al. 2002/. However, most of the macro- and micronutrients required by plants are supplied by mineralization of organic matter in the soil. However, see discussion concerning phosphorus in Section 9.

Litter production

Litter production originates from both above- and below-ground components, where the largest annual inputs are from needles/leaves and fine roots /Chapin et al. 2002/. Below-ground litter production from roots and mycelia mainly enters the humus and the mineral soil layers and is roughly proportional to the root distribution in the soil. Litter production provides the soil compartment with organic material and is roughly proportional to the production of the ecosystem (see Chapter 6). Litter production is also affected by natural disasters, such as storms, which may cause a large increase in litter production, with regard to both more easily decomposed parts such as leaves and branches /Mjöfors et al. 2007/ but also less easily decomposed parts such as stems.

Heterotrophic soil respiration

The flux of carbon (CO_2) from the soil, i.e. soil respiration, can be divided into autotrophic respiration, by roots and mycorrhiza (carbon from autotrophs), and heterotrophic respiration, by microbes and soil fauna. Heterotrophic respiration is decomposition, where organic matter is converted into inorganic nutrients and CO_2. Biomass, with e.g. assimilated radionuclides, that is turned into litter is quickly decomposed and creates an excess of radionuclides in comparison with carbon in the humus and upper mineral soil layer. The fate of this enrichment depends on the strength of the chemical interaction with the solid phases of the different soil horizons (e.g. Tipping 1996). The balance between decomposition and NPP strongly influences the carbon cycle as well as other element cycles at both ecosystem and global scales.

Coarse woody debris is more slowly degraded than leaf and needle litter. The turnover rate of *Picea abies* logs was investigated by /Næsser 1999/ in southeastern Norway. He found that the decomposition of dead wood was significantly affected by cross-section diameter, ground contact, soil moisture and aspect. The overall average decomposition rate constant was 0.033 per year with a minimum of 0.017 and a maximum of 0.049 per year. The coarse woody debris pool, with a comparably longer turnover time than the litter pool, is generally small in most well-managed forests today.

In poorly inundated soils, such as wetlands, where oxygen is depleted by aerobic decomposition, methane is a second path of emission of carbon to the atmosphere. However, the magnitude of this emission is small compared with the emission of carbon as CO_2 and constitutes approximately 5 to 15% of the carbon emitted as CO_2. /Chapin et al. 2002/.

Other gases that may leave the soil compartment are NH_3, N_2 or N_xO_x. The NH_3 flux is low in most ecosystems but may be high where NH_4^+ accumulates due to nitrogen input from animals or human management, i.e. grass ecosystems or arable land /Chapin et al. 2002/. Nitrification and denitrification are associated with a loss of nitrogen. The loss during nitrification is more or less proportional to the rate of nitrification, where small amounts of nitrogen are lost as gas. Denitrification is typically high under conditions of low oxygen concentrations, high nitrate concentrations and a supply of organic carbon /Del Grosso et al. 2000/. Generally, the nitrogen loss from these fluxes is low and has a limited effect on the ecosystem pool of nitrogen. These fluxes may, however, be significant in some ecosystems under certain conditions or events, i.e. fires.

Atmospheric deposition

Another source of element input to the ecosystem, and eventually the soil compartment, is atmospheric deposition of e.g. nitrogen and sulphur deposition. Locally, this deposition may be high, due to eolic deposition of soil, e.g. close to large areas of arable land. This deposition may be further augmented by deposition from sea spray, containing mainly cations such as I, Br, Cl and Na, in regions close to the sea.

Water fluxes

The downward flow of water in the soil profile (infiltration and percolation) results in a leaching of substances and a transport of e.g. humic acids downward in the soil profile. This vertical transfer of materials through soils generates distinctive profiles such as podzols. Soluble ions, originating from mineralization, weathering or atmospheric deposition, move downward. This downward movement of elements continues until the chemical environment causes them to become reactants in chemical processes that form compounds. With regard to DOC, leaching from the humus horizon was quantified at three localities as comprising between 6 and 19% of the total carbon input to the humus layer /Berggren Kleja et al. 2007/, but a major part is decomposed within a short time /e.g. Cleveland et al. 2004/. The DOC becomes less mobile in lower soil horizons /Neff and Ashner 2001, Berggren et al. 2003/, where non-humic hydrophilic substances that are considered more easily biodegradable dominate the soil organic matter (SOM), while humic substances, also rich in N, are bound in soil sorption processes /Neff and Ashner 2001/. This fraction is probably a substantial part of the carbon that is retained over time in woodland soils. Other substances that are leached consist mainly of silicon, aluminium and iron ions that are bound as hydroxides and oxides in lower soil horizons.

5.2 Interactions with other ecosystems

The most important process for transport among terrestrial and aquatic ecosystems is the process mediated by water flow. Apart from water flow, few processes are available for transport across different terrestrial ecosystems. Wind transports small amounts of particles and deposits them as dry deposition, e.g. soil erosion and sea spray. The water-mediated transport from terrestrial systems to aquatic systems is seasonally highly variable, reaching a maximum in spring and autumn /Tröjbom et al. 2007, 2008/. Although the net transport of elements on a landscape scale is from terrestrial to aquatic systems, the reverse transport may be substantial on a local scale, e.g. deposition of organic material on sea shores.

5.2.1 Transport from terrestrial to aquatic ecosystems

The lateral flow of water (Figure 5-1) is large enough to transport substances. The water originates from precipitation that infiltrates through the surface and reaches the saturated zone and is further transported into streams and lakes. The unsaturated overland flow is assumed to be negligible in quantitative hydrological modelling /Bosson et al. 2008/, but may in extreme cases of downpour generate substantial transport of organic matter. Moreover, transport among terrestrial ecosystems (wetlands excluded) is considered to be of minor importance compared with the actual element fluxes within an ecosystem. However, transport to and from wetlands (here considered a terrestrial system) may be of significance for accumulation of allochtonous matter /Tröjbom et al. 2007, 2008/, where e.g. carbon is mainly transported as DOC but also as particulate organic carbon /Canham et al. 2004, Tröjbom et al. 2007, 2008/. Wetlands have been called the kidneys of the landscape because of their ability to filter and retain nutrients and contaminants /Mitsch and Gosselink 2000/. Similarly, a number of elements are transported from the land to the sea, where several factors – such as cation-anion exchange capacity, microbial mineralization and the amount of water flowing through the soil profile – influence this transport.

5.2.2 Transport from aquatic to terrestrial ecosystems

Transport of elements can occur from aquatic ecosystems to terrestrial ecosystems (mainly wetlands). Floodplains and riparian swamps and marshes are often inundated by rivers, streams or other water bodies and affected by overbank sedimentation. In this manner, elements associated with colloids and particles in the water are transported to the wetlands and retained. These wetlands can therefore function as sinks for nutrients and contaminants /Mitsch et al. 1979, Walling and Bradley 1988, Burrough et al. 1999, Stark et al. 2006/. Similarly, deposition of organic material from the sea, marine residues, may be substantial along shorelines.

Transport of materials and nutrients may also be mediated by biota. /Willson et al. 1998/ described this for the Pacific coastal region of North America, where anadromus fish such as salmon, char, and smelt travel every year from the ocean into freshwater streams to spawn. These fish provide an important resource for terrestrial predators like birds of prey and bears. A large amount of fish is consumed by terrestrial vertebrates and evertebrates, and /Willson et al. 1998/ estimated the potential input of P to the terrestrial ecosystems to be 6.7 kg/ha.

5.3 Disturbances at the ecosystem level

Disturbances on large spatial scales, such as fire, affect the element pools and fluxes in the ecosystem. All above-ground biomass, litter and a major part of the humus layer can be removed in this way. Consequently, a severe fire may convert a large proportion of carbon and nitrogen into carbon dioxide and volatilized nitrogen. This means that the effect of a fire is a release of other elements now available to the next generation of biota or flushed away with the increased runoff, ending up in streams. A less drastic variant of this occurs after a clear-cut /Likens and Borman 1995/, where the affect on the litter and humus pool is less drastic. Most terrestrial ecosystems are affected by fire, although the fire interval may differ substantially, e.g. deciduous stands on south-facing slopes, *"lövbännor"*, moist Norway spruce forests and bogs (with decreasing fire interval). A decreasing fire interval would generally suggest less time for accumulation of organic material, both in regard to biomass and SOM. The fire-adapted Scots pine forest on a shallow soil layer with a high fire frequency and the bog with a low fire frequency would be the two extremes on a continuous scale with regard to the potential release of radionuclides accumulated in organic material.

A heavy storm, where most of the biomass is left as organic material, would potentially prolong the time period for increased decomposition, but would not necessarily lead to an increased transport of elements to the surrounding streams as in the case of a severe fire.

5.4 Concluding remarks

The conceptual model makes it possible to identify pools of contaminants that are of potential interest to the risk assessment. These pools may have the potential of either becoming large and thereby comprising a potential sink for contaminants or becoming available to biota and being further transported up in the food web. Organic matter is accumulated mainly in the vegetation or in the soil. The allocation of organic matter in the vegetation is either to tissue with high turnover, such as leaves, needles or fine roots of which only a fraction is available to larger biota, or to tissue with a longer turnover time, such as woody debris whose turnover today is mainly controlled by humans through commercial forestry. The soil organic matter (SOM) also has pools with different turnover times, but may be accumulated under much longer time periods. The behaviour of both vegetation and SOM pools is typically determined by a number of fluxes, and the relationship between these regulates the size of the pools. Generally, NPP sets the upper limit to the potential input of organic material, whereas decomposition describes the major loss of organic material. By being able to describe these regulating fluxes, it is possible to understand how and under what circumstances pools may act as sinks or sources for organic matter, elements or radionuclides. A quantification of these pools and fluxes will further improve an understanding of accumulation and turnover. Such an understanding will be further enhanced in the following chapters by combining data from field investigations and dynamic modelling from the Forsmark and Laxemar-Simpevarp areas. This will also permit comparisons among alternative ways of describing pools and fluxes on different spatial and temporal scales.

6 Field-estimated pools and fluxes of carbon in various ecosystems

6.1 Introduction

Six ecosystems in Forsmark and Laxemar-Simpevarp were investigated with regard to pools and fluxes of carbon using field estimates. The investigated ecosystems represent vegetation types that have been considered to be important both with respect to area coverage and as potential sinks for organic matter. Accordingly, conifer forests and forested wetlands have been studied both in Forsmark and in Laxemar-Simpevarp. The aim was to quantify pools and fluxes, which will serve both as a way of describing these ecosystems more closely with regard to organic matter from a site-specific perspective, and also as a baseline for comparison with the modelling work presented in Chapter 7 and to compare these site-specific estimates with more general literature data that may be used to describe pools and fluxes in long-term perspectives in the safety analysis.

6.2 Methods and data

The ecosystems are illustrated by the pools and fluxes in Figure 5-1, and a description of these is found in the previous chapter (Chapter 5). In comparison with the previous chapter some fluxes have been omitted, but these changes are explained in the text below. In the following calculations we have omitted all fluxes assigned to consumers (presented in Section 4-2), which are introduced in the landscape scale budgets in Chapter 8. One reason for this is a combination of their mobility and a more coarse-grained resolution of data.

6.2.1 The ecosystems

The investigated ecosystems are presented in Table 6-1 and Figures 6-1a and b, and are further characterized in Table 6-2.

Table 6-1. The six investigated localities in the Forsmark and Laxemar-Simpevarp areas.

Site	Forest type	SKB ID code	Report code	X-coordinate	Y-coordinate
Forsmark	Norway spruce	AFM001247	B2a	6698733	1633420
	Norway spruce	AFM001068	FG1	6698152	1633558
	Alder swamp forest	AFM001076	SS1	6698060	1633495
Laxemar-Simpevarp	Oak forest	ASM001426	L1	6367828	1552003
	Norway spruce	ASM001440	G1	6369225	1547128
	Alder shore forest	ASM001434	S1	6367881	1551023

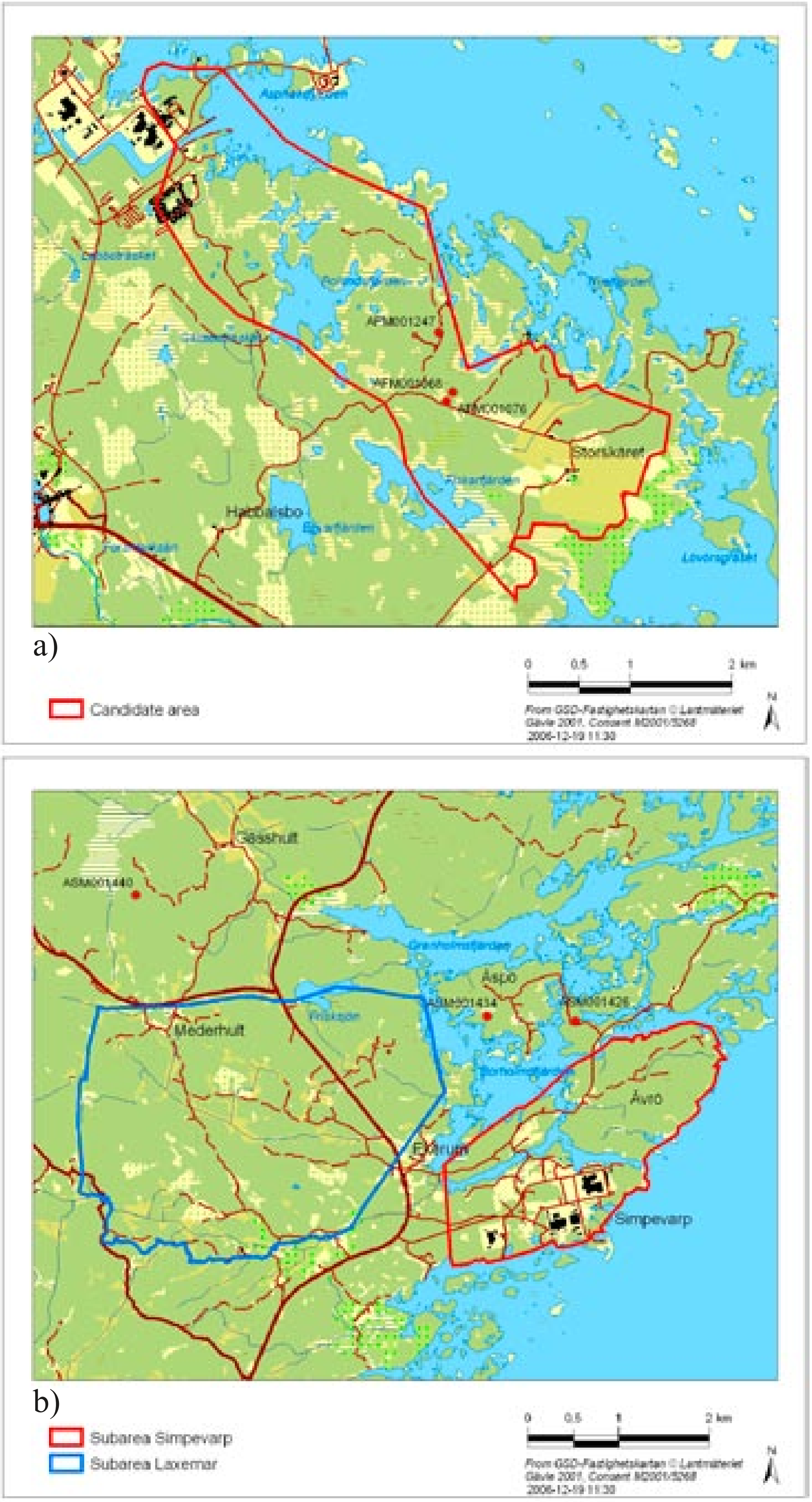


***Figure 6-1.** The investigated localities for carbon pools and fluxes in (a) Forsmark and (b) Laxemar-Simpevarp. Codes are described in Table 6-1.*

Table 6-2. Characteristics of the investigated localities in the Forsmark and Laxemar-Simpevarp areas (see table 6-1 and pictures in Appendix 8).

Properties	**Forsmark localities**			**Laxemar-Simpevarp localities**		
Report code	**B2a**	**FG1**	**SS1**	**L1**	**G1**	**S1**
Soil depth (m)						
Soil moisture class[1]	Fresh	Fresh/moist	Moist	Fresh	Fresh	Moist
Soil pH (H_2O), H 0–30[1]	–	6.7	6.7	–	3.9	5.3
Soil pH (H_2O), M 0–10[1]	7.0*	7.2	7.1	5.3	–	–
Soil pH (H_2O), M 10–20[1]	7.0*	7.4	7.4	4.9	–	–
Soil pH (H_2O), M 55–65[1]	7.6*	7.9	7.7	5.2	–	–
Soil type[1]	Leptosol	Regosol/Gleysol	Gleysol	Histosol/Gleysol	Histosol	Histosol
Stone/boulder volumetric content in M 0–30 (%)[1]	62*	50	66	57	0	0
Number of trees/ha[2]	1,340	780	3,340	200	400	1,600
Basal area (m^2/ha)[2] *Picea abies, Betula pendula, Alnus glutinosa, Pinus sylvestris, Quercus robur*.	22.5 (P. a.)	20.5 (P. a.), 6.5 (B. p.)	5.3 (B. p.), 7.33 (P.a.), 3.0 (A. g.), 2.3 (P. s.)	15.0 (Q. r.)	15.5 (P. a.)	17.5 (A. g.)
Tree age (2–3 trees)[2]	69–70	90–98	97–108	107–136	57–67	44–55
Tree height (m)[2]	16.3	19.8	18.5	17.1	21.0	11.6
Dominant height at 100 years /Hägglund 1973/.	G 20	G 20	(G 18)	EK 18	G 28	–
Diameter at breast height (dbh in cm)[2]	0.21	0.26 (*P. a.*)	0.31 (*P. a.*, n=5)	0.36	0.32	0.14
Veg. Types /Nordiska ministerrådet 1998/	Coniferous, Calluna-Empetrum-type	Coniferous fern type	Alnus swamp herb type	Herb rich oak forest	Coniferous Vaccinium myrtillus type	Alnus shore forest type
Field-layer species[1]	Low herbs without shrubs	Tall herbs without shrubs	Low herbs without shrubs	Broad leaved grass type	Bilberry type	Broad leaved grass type
Bottom-layer species[1]	Mesic mosses type	Mesic mosses type	Mesic mosses type	Mesic mosses type	Mesic mosses type	–

*Measured 100 m from the locality 1) /Lundin et al. 2004 and 2005/ 2) /Tagesson 2006a/.

6.2.2 Estimation of pools and fluxes

A large number of different data sources have been used to put together the ecosystem descriptions. Generally, the aim was to use site-specific data whenever possible, but in some cases such data were lacking and regional or literature data were used instead.

Tree layer

Biomass

Tree layer data for the different localities were derived from tree height and breast height diameter measured for ten representative trees at each locality /Tagesson 2006a/. For conifer trees (*Picea abies* and *Pinus sylvestris*) and birch (*Betula* sp.), Marklund's equations were used to calculate fractions of green tissue, stem and living branches /Marklund 1988/. For alder (*Alnus glutinosa*), the equations presented in /Johansson 2000/ were used. The stump, coarse roots and fine roots down to Ø 5mm and between 5 mm and 2 mm were calculated using functions presented in /Petersson and Ståhl 2006/, where birch root functions were also used for alder. Fine root biomass estimates for diameters < 2mm were available for each locality /Persson and Stadenberg 2007a/ (see Section 4.1.3). These estimates were not corrected for stone and boulder content at the localities /Persson and Stadenberg 2007a/. Deciduous leaf biomass was estimated using a function derived from *Betula lenta* /Martin et al. 1998/. For oak (*Quercus robur*), equations presented in /Balboa 2005/ were used to describe the oak's above- and below-ground biomass. It was, however, unclear whether fine root biomass were included in derivation of the equations by /Balboa 2005/, and the field estimates of fine root biomass for roots with a diameter less than 2 mm were added to the calculated estimates.

Mean biomass and standard deviation were estimated for each tree compartment (Figure 5-1) using the sample trees. These derived average tree estimates were adjusted to the stand level of the locality by dividing by the average tree cross-sectional area (m^2) and multiplying by the average basal area ($m^2 \cdot ha^{-1}$), resulting in a basal-area-weighted mean and standard deviation /Tagesson 2006a/.

Net primary production

NPP is defined here as the sum of all materials that have been produced and are retained by live plants at the end of the interval and the amount of organic matter that was both produced and lost by the plants during the same interval /Clark et al. 2001/. The calculation of total NPP therefore includes estimates of biomass increment and biomass loss. Above-ground litterfall was estimated at five localities during two consecutive years /Mjöfors et al. 2007/. Litterfall at the sixth locality, the alder forest S1, was estimated from the average stand leaf biomass and by adding the branch and reproductive tissue fall from the mean fraction of leaf fall from three stands presented in /Raulo and Hokkanen. 1989/. Fine root production and turnover were estimated at one locality, the Norway spruce stand FG1 in Forsmark, see Section 4.1.3 /Persson and Stadenberg 2007b/. They estimated the turnover for fine roots (diameter fractions less than 1 mm), which represent the fraction with the highest turnover /Persson and Stadenberg 2007b/, to be 0.6–0.7 y^{-1}. This estimate is regarded as conservative, due to the fact that only significant changes between four sampling occasions were used. They were not able to quantify a statistically significant turnover for larger diameter fractions (2 mm < Ø < 10 mm) /Persson and Stadenberg 2007b/.

A review of literature data from various forest stands, obtained by sequential coring, suggests annual turnover rates of 1–2 times the average fine root biomass. The mean for root diameters <1 mm was 1.0 (min=0.1, excluded from the mean, and max=1.7) and the mean for root diameters <2 mm was 1.5 (min=1.0 and max=2.4) /Persson and Stadenberg 2007b/). In the calculations, we assume that the fine root production at all six localities is 1.0 the biomass for the fraction < 2 mm. Turnover of larger root fractions was neglected, but by using a somewhat higher turnover rate than the estimated one this should partly be compensated for. Net stem increment was not measured at the localities, but was obtained from the National Forest Inventory database for a regional area around the sites. Stem increment data were extracted using a number of selection criteria fitted to each locality (Table 6-3), which resulted in a number of similar NFI sampling plots with estimated net stem increment. This increment was converted to dry matter per unit area using Table 6-4. Stem increment from each plot was the mean of five years, and a span of 6 to 16 plots was used to estimate the statistics for stem increment for each locality. The increment in branch and coarse root biomass was estimated using data from /Berggren et al. 2004/, where the mean ratio between branch/stem and root/stem increment was calculated from 18 plots. This ratio was applied to the stem increment estimates of the localities. The increment of leaf/needle and fine root biomass were assumed to be zero.

Table 6-3. Selection criteria that were used to extract data for stem increment for each of the six localities from a subsample of the NFI database covering Forsmark and Laxemar-Simpevarp. Age (year) is based on tree rings at breast height.

Locality	Selection criteria	N	Year
B2a	age (60<x<80), mean height (140<x<180) and spruce proportion (0.6<x)	9	1985–1993
FG1	age (85<x<105), mean height (180<x<220) and spruce proportion (0.5<x<0.9).	11	1985–2001
SS1	age (>74 OCH <130), mean height (>=160 OCH <=200) and "Wet -92|Moist 93-" (in *Sw. "Blöt -92|Fuktig 93-").*	9	1993–2005
L1	age (100<x) and oak proportion (0.6<x).	9	1985–2005
S1	age (39<x), pine proportion (x=0) and "Wet -92|Moist 93-" (in *Sw. "Blöt -92|Fuktig 93-").*	6	1993–2005
G1	age (44<x<76), mean height (180<x<230) and spruce proportion (0.6<x)	16	1983–2001

Table 6-4. Overview of studies providing data to this study.

Functional unit	Property	Part	Area (m^2)	Time (y)	Year of data set	Reference
Tree layer	Biomass	Above-ground	400	1	2005	Partly in /Tagesson, 2006a/
		Coarse root	400	1	2005	Partly in /Tagesson, 2006a/
		Fine root <2mm	120	1	2004	/Persson and Stadenberg 2007a/
	NPP	Wood 1)	150–300	5	1985–2005	/NFI 1985–2005/
	Litterfall		150	2	2004–2006	/Mjöfors et al. 2007/
	Root litter production <2mm		120	1	2004–2005	/Persson and Stadenberg 2007b/
Field and bottom layer	Biomass/NPP		120	1	2004	/Löfgren 2005/
Fungus mycelia	Biomass/NPP		120	1	2004	/Persson and Stadenberg 2007a/
SOM	Litter		120	1	2004	/Löfgren 2005/
	Humus/soil		225	1	2003–2004	/Lundin et al 2004, 2005a/
	Woody debris		Tree stand	1	2004–2005	/Andersson 2004, 2005/
Heterotrophic resp.			900	1	2004–2006	/Tagesson 2006b, 2007/

1) Not measured at the locality, but averaged for several similar localities.

Field and bottom layers

The above-ground (AG) biomass for the field and bottom layers was investigated by collecting and measuring the biomass at the time of peak biomass. NPP for the field layer was estimated by assuming that all biomass, except perennial tissue, was produced during the year of the investigation. NPP for the bottom layer was estimated by measuring bryophyte shoot elongation at five plots on each locality in 2004 (bryophytes dominated the bottom layer) /Löfgren 2005/. AG biomass for the sixth locality, B2a, was estimated using a regression equation between AG and below-ground (BG) biomass (see below) for the other 5 localities (Spearman $r = 0.90$, $n=5$, $p=0.037$) and applying that equation to B2a using the BG biomass (below) as a predictor for the AG biomass. The standard deviation was calculated using the mean Coefficient of Variation for the five localities.

BG biomass of fine roots was estimated by /Persson and Stadenberg 2007a/ who distinguished between tree and field layer roots in their estimates. The same location of plots was used as in the study of the field layer, making it possible to directly relate measured above- and below-ground biomasses of the field layer.

Field layer litter production was assumed to be equal to the AG NPP plus the BG fine root fraction (Ø <2 mm) that was assumed to be replaced during the year, and the bottom layer production. Consequently, it was assumed that the field and bottom layers had a negligible annual biomass accumulation in the six localities.

EM fungi

Estimates of biomass and NPP for ectomycorrhizal (EM) mycelia were based on a study by /Wallander et al. 2004/ in a Norway spruce forest in southern Sweden. The results of /Wallander et al. 2004/ suggested that the mean mycelia biomass was 53% of the total fine root biomass (mycorrhizal sheath excluded, here included in the fine root biomass) and the NPP was 8% of the fine root biomass. Their production estimate, mycelia growth into sand-filled mesh bags, was adjusted according to /Hendricks et al. 2006/ by multiplying the mycelia production in sand by three to adjust to mycelia production in soil. Turnover of mycelia was assumed to approximate the biomass/NPP ratio, indicating a steady state of mycelia biomass between years, and resulted in a turnover time of approximately 2 years. EM mycelia estimates were assigned to all six localities using the tree fine-root biomass, although the underlying investigation of mycelia may not be considered to represent the wetter sites such as the alder swamp forest and the alder shore forests.

Woody debris and litter

Coarse woody debris, such as standing and fallen logs, was quantified in volume by /Andersson 2004, 2005/ in all vegetation types with a tree layer according to the vegetation map of both sites. Litter layer thickness was investigated in five out of six localities /Löfgren 2005/. It was therefore possible to obtain specific measurements for five of the localities. The sixth locality, B2a, was assigned the same value as FG1 due to their similarities.

Soil Organic Carbon (SOC) pool

The soil organic carbon (SOC) pool was estimated for each locality, making a total of eight lateral transects of one humus and three mineral soil samples down to approximately one metre below the surface in each replicate, using the same methodology as the National Forest Soil Inventory /Lundin et al. 2004, Lundin et al. 2005a/. Soil microbes were not accounted for separately, but were included in the total carbon content of the soil. However, some generic data describing biomass for soil fauna are presented in Table 4-45.

C-mineralization

Soil respiration was measured during one year in 2004/2005 or 2005/2006 for Laxemar-Simpevarp and 2005/2006 for Forsmark in the different vegetation types, using a closed chamber technique, along with measurements of soil temperature and soil moisture (further described in Section 4.2.4) /Tagesson 2006b, 2007/. The annual soil respiration was estimated for each vegetation type using a regression between soil temperature and the measured soil respiration (Table 4-46). /Högberg et al. 2001/ presented data from a boreal forest (Pinus sylvestris) in northern Sweden, suggesting that the contribution of root-mycorrhizal respiration was between 52–56% of total soil respiration. They also showed that this relationship seemed to be fairly stable during the measurement period. Accordingly, 50% of the measured mean annual soil respiration was considered to be caused by C-mineralization across the vegetation types.

Omitted fluxes

Some fluxes have been omitted due to their low contribution to the overall budget. Studies of volatile and soluble components above ground suggest that these components constitute an insignificant loss of the forest NPP /Clark et al. 2001, Persson and Nilsson (ed.) 2001/. No estimates of root exudates are known at the forest stand level, and this flux is therefore left for further investigations.

Ecosystem emergent properties

Changes in the total carbon stock of a forest stand, net ecosystem exchange (NEE), can be estimated by adding together the changes of the carbon stock in vegetation and soil. The change in carbon stock in the vegetation was calculated by adding biomass increase and litter production in the tree, field and bottom layers during a year. The change in the carbon stock in the soil was calculated as the difference between litter production (above- and below-ground) and heterotrophic respiration. It is assumed that import and export of carbon (e.g. dissolved organic carbon) is negligible (see Sections 5.2 and Table 8-7, 8-8).

The spatial and temporal extent of the different estimates

The site measurements were only conducted during a limited time period, in most cases one year. The calculated variation (standard deviation) therefore only represents the spatial variation during a particular year. For the estimate of the above-ground litterfall that covered two years, a mean of the standard deviation was calculated to represent the mean spatial variation within a year. The exception is the mean of the stem increment, which is based on the mean increment for five years from each locality. These localities were sampled in different years (Table 6-3). The spatial scale on which the measurements have been conducted is between 100 m^2 and 900 m^2 (Table 6-4).

Carbon concentrations and transformation factors

Carbon concentrations for different plant species and functional parts of species, i.e. wood and green tissue, were estimated in four studies. Three of these were conducted in Forsmark covering the field layer /Fridriksson and Öhr 2003/, fungal mycelia /Johanson et al. 2004, 44%/ and a more extensive study covering three vegetation types and a number of mammals /Hannu and Karlsson/. One was conducted in the Laxemar-Simpevarp area and was similar to the more extensive study conducted in Forsmark /Engdahl et al. 2006/. The results from /Hannu and Karlsson 2006/ and /Engdahl et al. 2006/ are presented in Table 6-5, which shows the results of merged data from both sites. Generally, woody compartments have a lower carbon content than leaves/needles and fine roots /Scarascia-Mugnozza et al. 2000, Skogsstyrelsen 2000/ (see Table 6-6). This was not found when using data from Table 6-6, probably due to the low sample sizes. However, in the calculations woody compartments were assigned a carbon content of 0.48 while green and fine root compartments were assigned a carbon content of 0.50 of the dry weight.

The average carbon content of fresh needle litter, obtained by gently shaking a number of branches on each locality, was 46.8% for the five different localities. This relative carbon content remained stable during two years of decomposition in litter bags on the ground /Mjöfors et al. 2007/. This figure was also in close agreement with the figure measured at one locality in Forsmark by /Fridriksson and Öhr 2003/ Table 6-7. Consequently, this figure was used to describe the carbon content of the litter pool and of woody debris.

Coarse woody debris volume was converted to dry weight using data from /Benediktsson et al. 2005/ (Table 6-8). Conversion of dry weight to carbon for decaying wood is dependent on the decay stage of the wood. Here the same conversion factor as for litter is used for the carbon concentration in the dead wood.

Table 6-5. Measured carbon concentrations (% of dry weight) from the Forsmark and Laxemar-Simpevarp areas sorted according to tree species and type of layer /Engdahl et al. 2006, Hannu and Karlsson 2006/.

Species/groups		mean	median	sd	N
Norway spruce	Green	52	53	2	4
	Wood	48	52	7	4
	root	55	57	7	10
Oak	Green	52	52	1	2
	Wood	41			1
	root	48	50	4	3
Alder	Green	49			1
	Wood	45			1
	root	44			2
Field layer	Green	46	46	0	7
Shrub layer	Green	53	51	5	5
Bottom layer	Bryophyte	50	49	3	7

Table 6-6. Carbon concentrations (% of dry weight) in some common tree species /Skogsstyrelsen 2000/. Carbon concentrations in roots are from /Alriksson and Eriksson 1998/.

Tree species	Stem	Branch	Needles	Root
Picea abies	48	59	49	48
Pinus sylvestris	49	51	51	48
Betula pendula	48	59	49	48
Other deciduous trees	49	49	49	*48

*Same value as *Betula pendula*.

Table 6-7. Mean carbon concentrations (% of dry weight) in plant materials in a Scots pine forest in Forsmark /Fridriksson and Öhr 2003/.

Component	N	Mean (SE), %
Field layer, green components	6	46.1 (0.2)
Field layer, brown components	6	45.7 (0.4)
Ground layer (Bryophytes)	6	43.9 (0.5)
Litter	6	46.2 (0.2)

Table 6-8. Biomass expansion factors for conversion from volume (m^3) to biomass (tonnes of dry matter /Benediktsson et al. 2005/). Stem biomass refers to stem and bark biomass above stump height. One m^3 of stem wood corresponds to the value in column 2 as tonnes of dry matter.

Species	Density
Pinus sylvestris	0.41
Picea abies	0.41
Broad-leaved	0.50
All trees	0.42
Dead trees	0.43

6.3 Results and discussion

The components of the ecosystem carbon model for the six localities are presented in Table 6-9.

6.3.1 The ecosystems

The pools and fluxes within the different ecosystems are discussed below.

The Norway spruce forest (B2a and FG1) in Forsmark

The younger stand (B2a) had a lower NPP than the older stand (FG1) but accumulation in biomass was higher, which means that the higher NPP is offset by higher litter production in the older stand. The denser young stand had much less biomass in the field layer than the older forest. The SOC pool was much smaller in the younger forest, which is largely attributable to a shallow soil layer with a high boulder frequency. Heterotrophic respiration was estimated to be 36% higher in the older stand, which also had a 37% higher litter production (47% and 52%, respectively, for G1 below). Both stands had a net change of the SOC pool that is close to zero.

Table 6-9. Mean carbon pools (±sd) for different components in the six investigated ecosystems at Forsmark and Laxemar-Simpevarp. The soil carbon pool is restricted to a depth of approximately 1 metre, except for B2a where there was only a shallow mineral layer on top of rock. The EM mycelia estimates are not included in the calculations of ecosystem emergent properties at the end of the table. Pools are in gC m^{-2} and fluxes are in gC m^{-2} y^{-1}.

			Forsmark			Laxemar-Simpevarp		
Functional groups and properties			**B2a**	**FG1**	**SS1**	**L1**	**S1**	**G1**
Tree layer	Biomass	Needles/leaves	677±263	593±453	326±305	233±87	97±56	421±116
		Wood	6,577±2,051	9,074±3,716	5,411±2,120	5,372±1,956	6,035±4,116	5,024±606
		Fine root <2mm	183±76	205±104	166±108	90±46	41±42	250±88
	Net acc	Branches	26±4	23±10	20±9	30±12	25±13	40±23
		Stems	114±19	99±41	88±41	129±52	107±57	172±100
		Coarse roots	29±5	25±10	22±10	32±13	27±14	43±25
	Litterfall		64±26	91±19	108±32	136±33	115±42	184±65
	Root litter production <2mm		183±76	205±104	166±108	90±49	41±42	250±88
Field and bottom layers	Biomass	Leaves	8±6	20±12	3±3	45±12	15±14	4±4
		Bryophytes	38±16	38±16	43±47	26±27	–	62±47
		Roots <10mm	29±35	98±115	22±47	137±121	38±53	9±26
	Litter prod.[1]		39±29	94±50	25±22	175±102	46±46	47±23
EM	Biomass		62	74	55	32	12	87
mycelia	Litter prod.[2]		28	33	25	14	5	39
SOC	Litter pool		544±228	544±228	383±130	294±79	507±116	746±507
	Humus		1,660	1,620	2,440	–	30,960[3]	59,700[3]
	Mineral soil		530	5,330	1,720	6,260	–	–
Heterotrophic respiration			290±125	395±620	225±190	590±490	365±310	425±400
Total	NPP		454±87	537±124	429±122	591±129	360±102	736±154
	Litter prod.		285±85	390±117	299±114	401±126	202±83	480±112
	Acc. soil		–5±151	–5±631	74±222	–189±506	–163±321	55±415
	Acc. veg		169±20	147±44	130±93	190±55	158±60	255±106
	NEP		164±153	142±632	204±226	1±507	–5±326	311±415

[1] Includes field layer above-ground and below-ground, and bottom layer NPP. [2] Not included in properties under Total. [3] Peat soil.

The alder swamp forest in Forsmark (SS1)

The alder swamp stand in Forsmark had a higher carbon content in the humus layer compared with the two other stands in Forsmark. On the other hand it had a low carbon content in the mineral soil, where it also had the highest stone/boulder content of all of the investigated localities. This locality had the highest allocation of organic matter to the soil, which should be expected due to the periodically water-logged conditions. The lack of peaty soil, the high input of litter during the measured years and low heterotrophic respiration suggest that this area may have a relatively short history of being a water-logged area and/or have large variation between years with regard to soil moisture, which is expected to limit heterotrophic respiration in this vegetation type.

The alder shore forest in Laxemar-Simpevarp (S1)

The alder shore forest is situated on histosol and is periodically water-inundated. It would therefore be expected to be a sink for carbon, contrary to the result. A low leaf biomass in comparison to the other localities is in agreement with a lower, independently sampled root biomass. /Raulo and Hokkanen 1989/ presented litterfall data for three alder stands in the interval 89–145 gC m^{-2} y^{-1}, which accords well with the estimate in Table 6-9. In comparison, the CoupModel arrived at a higher estimate of NPP and a much lower estimate of heterotrophic soil respiration (Table 6-10, see Section 4-3 for a presentation of this model). This locality is

Table 6-10. The CoupModel was used to model two of the localities in Laxemar-Simpevarp, the alder shore forest and the Norway spruce forest (Fig 4-27b, d /Karlberg et al. 2006/). Input data from the localities were soil properties, soil carbon and nitrogen content. A negative sign indicates net emission. Fluxes in gC m^{-2} y^{-1}.

Property	Alder shore forest (S1)	Norway spruce forest (G1)
NPP tree layer	350	690
NPP field layer	180	160
NPP total	530	850
Heterotrophic soil respiration	300	930
Litter production	440	540
Net ecosystem exchange	230	–80

situated in a depression in close connection with a sea bay, and the water table in this forest is probably highly variable due to the surrounding hydrology as well as water level fluctuations in the sea. This suggests that soil respiration may fluctuate heavily, and thereby its potential of being a carbon sink or source. /Kutsch et al. 2001/ found unexpectedly high soil respiration in an alder stand during a period with a low water table. The net result during a somewhat longer time period should in any case be that the alder seashore is a sink for carbon until hydrological conditions cease being the main restrictor for heterotrophic respiration.

The oak forest (L1) in Laxemar-Simpevarp

The litterfall was estimated to be much less than the leaf biomass, which can partly be explained by the fact that broad-leaved trees become approximately 22% lighter in connection with senescence in the autumn /Viro 1955/. (This is, however, not applicable to alder). Another contributing factor to the missing leaves is that this locality is situated close to the sea, fairly exposed to wind, and might therefore export carbon as leaves to the sea during the stormy autumns. Another explanation could be that the biomass expansion factors for oak (from Spain by /Balboa 2005/) underestimate the leaf biomass under Nordic conditions in a fairly open habitat.

The SOC pool almost completely lacked a humus layer, although it had the second highest litter production of the six localities. This indicates high bioturbation, which was confirmed by /Persson et al. 2007/. This locality also had high soil respiration, which was greater than litter production, making the soil a large source of carbon. This could be explained by an underestimation of the autotrophic part of the soil respiration in this old stand, which can be much higher than the 50% assumed here. If heterotrophic respiration would approximate litter production, heterotrophic respiration would constitute 34% of the total soil respiration. /Bolstad et al. 2004/ also found high soil respiration values for a deciduous tree stand (between 820 and 1,210 gC m^{-2} y^{-1}) in Northern Wisconsin, USA. The oak stand had the lowest tree density (Table 6-2) and consequently a large biomass in the field layer. This locality has a history as semi-natural grassland with large sparsely distributed oaks. From this perspective this locality is somewhat different from the other localities.

The Norway spruce forest in Laxemar-Simpevarp (G1)

During the measurements of litterfall in the Laxemar-Simpevarp area, this region was hit by the storm "Gudrun" in January 2005, which caused a somewhat higher litterfall for G1 during that year /Mjöfors et al. 2007/. The reason that G1 was more heavily affected than the oak locality was because "Gudrun" hit the region during the winter when the oaks were already defoliated. If the difference between the two years is adjusted using the average difference between year 1 and 2 from the three Forsmark localities /Mjöfors et al. 2007/, litterfall can be reduced by 48 gC m^{-2} y^{-1}. This would mean a somewhat reduced NPP and net accumulation in the soil that would be close to zero and similar to the other Norway spruce localities n Forsmark. The soil respiration measurements stopped in March 2005 and the increased litter production during January was probably not captured by the soil respiration measurements.

The NPP in the Norway spruce forest was high (689 gC m^{-2} y^{-1}), which was in accordance with the CoupModel estimate of the tree NPP for the same locality, Table 6-10 /Karlberg et al. 2006/. This is probably an effect of being a fairly young stand planted on drained peat soil. NPP in the field layer was however, heavily overestimated by the CoupModel. The estimated heterotrophic soil respiration was also of a similar magnitude, 850 gC m^{-2} y^{-1} and 930 gC m^{-2} y^{-1}, respectively, where the CoupModel estimated the heterotrophic respiration to be 45% of the soil respiration due to the high carbon content of the soil. The CoupModel was also able to show a net decrease in soil carbon, which would be expected as peat oxidizes under the aerobic conditions created after drainage (Table 6-10).

6.3.2 Ecosystem compartments and processes

This section compares and discusses pools and fluxes across the different ecosystems.

Tree layer

The tree layer carbon pool was sometimes larger than or similar in size to the SOC pool (see below). The tree layer contributed most to the ecosystem NPP and the tree trunks contained most of the carbon. Root turnover was only investigated at one locality, the Norway spruce forest (FG1), and this study was only able to detect a significant turnover of 0.7 y^{-1} of the fraction Ø < 1 mm. This is similar to what was presented by /Berggren Kleja et al. 2007/ for 40-year old Norway spruce stands (0.5–1). In this study, however, the turnover was adjusted to 1.0 y^{-1} and applied to <2 mm. This was done in order to include litter production from the larger diameter fractions. No studies have been able to estimate this fraction of the litter production, and the assumption of a turnover of 1.0 y^{-1} might lead to an overestimation of the actual root litter production.

Field and bottom layers

The field and bottom layers were small in comparison with other carbon pools, but they were important with regard to NPP and contributed between 6% and 29% of the total NPP (Table 6-10). These layers generally have a low ability to accumulate large carbon pools but have high production, and it is mainly the field layer that is available for browsing animals and humans (e.g. berry picking). The distribution of field layer roots is somewhat shallower than the tree root distribution and is mainly confined to the humus layer /Persson and Stadenberg 2007a/.

Ectomycorrhizal fungi

EM mycelia have not been included in the calculation of NPP, and they have so far been excluded in similar attempts to make carbon budgets, e.g. /Berggren Kleja et al. 2007, Schulze et al. 2000/. If it is assumed that secondary mycelial production requires photosynthates for production in a proportion similar to that for green plants (NPP approximately 50% of GPP), the corresponding GPP by the fungi (twice the secondary production) would constitute between 3 and 12% of the total ecosystem NPP. This fraction is commonly assumed to be a part of the vegetation GPP, or more specifically, the part of the soil respiration attributed to autotrophic and mycorrhizal respiration. Although few results are available, there is much to suggest that this carbon sink has generally been underestimated in other studies describing ecosystem budgets of carbon fluxes in forests or other ecosystems inhabited by mycorrhizal communities.

SOC

Swedish forests on Podzols under dry to slightly moist conditions have a mean SOC pool of 8,200 gC m^{-2} including the organic horizon (2,800 gC m^{-2}) and 0–0.5 m of the mineral soil /Olsson et al. 2008/. Similar figures were presented for two localities with Norway spruce forests with different soil moisture conditions, Knottåsen (1,270 gC m^{-2} and 5,230 gC m^{-2}) and Asa (2,340 gC m^{-2} and 8,820 gC m^{-2}), at similar latitudes as Forsmark and Laxemar-Simpevarp, respectively /Berggren Kleja et al. 2007/. The localities were, however, located inland. The four localities lacking peat soils are all below the average for Sweden, which seems reasonable with regard to the fairly young soils at both sites /Hedenström and Sohlenius 2008, Sohlenius and Hedenström 2008/. Peatlands in Sweden have an average carbon content of 260,000 g m^{-2} /Olsson 2000/. This value is higher than the values for the Norway spruce forest on drained peat soil and the alder shore forest located on peat soil in our study, and is probably more applicable to Sphagnum peat mires and bogs. Again, the accumulated peaty soils at the site are also expected to contain a smaller carbon pool than the average for Sweden due to the limited time for peat accumulation.

The flux of organic matter is highest to the humus pool (litterfall and fine root litter to the humus layer), whereas the largest carbon pool is generally found in the mineral soil /Olsson et al. 2008/. Estimates by /Bergren Kleja et al. 2007/ suggest that DOC originating from the humus layer and root litter in the mineral soil is of equal importance for the build-up of organic carbon in the mineral soil layer.

Heterotrophic respiration

The soil respiration fluxes for the oak forest and the Norway spruce forest in Laxemar-Simpevarp are large but not exceptional (see discussion in /Tagesson 2006b/). The high soil respiration in the Norway spruce forest is, however, caused by the underlying peaty soil, which is a remnant of an earlier drained peatland. Drainage and the growing forest have changed the conditions, leading to increased decomposition of the peat. A potential source of error is the generalization of how to divide soil respiration into heterotrophic respiration and root respiration. Estimates of the contribution of root respiration to total soil respiration vary from 10% to 90% /Hanson et al. 2000/. Here, the estimate of the heterotrophic fraction was based on a study by /Högberg et al. 2001/ of a boreal forest (*Pinus sylvestris*) in northern Sweden. They suggested that the contribution of root and mycorrhizal respiration to total soil respiration was 52–56%. For several reasons, this was also considered to be a conservative estimate. Accordingly, decomposition may be slightly overestimated in some localities but may also be underestimated in others, i.e. it is reasonable to assume that the heterotrophic component is underestimated in the Norway spruce forest standing on drained peatland, which would thereby constitute a source of carbon instead of a sink as shown in Table 6-9. This was confirmed in a simulation of the specific locality using the CoupModel, Table 6-10, /Karlberg et al. 2006/. Soil respiration is also discussed elsewhere (Section 4-3; /Tagesson 2006b, Tagesson and Lindroth 2007, Tagesson 2007/), but the general conclusion is that the estimates are in good agreement with other studies in similar areas.

Ecosystem fluxes

/Högberg et al. 2001/ showed that the flux of photosynthates has a large impact on soil respiration, and Figure 6-2 shows a positive correlation between the independently estimated fluxes of ecosystem NPP and soil respiration.

NPP was estimated to be between 360 and 736 gC m^{-2} y^{-1} for the different forest types at the two sites, where the alder shore forest in the Laxemar-Simpevarp area had the lowest NPP and the Norway spruce forest on drained organic soils in the Laxemar-Simpevarp area had the highest NPP. This is within the estimates presented by /Gower et al. 2001/ for boreal ecosystems (52–868 C m^{-2} y^{-1}, mean 424 C m^{-2} y^{-1}). All sites seem to have been carbon sinks during the measurement period (142–311 C m^{-2} y^{-1}) except for the oak forest and the alder shore forest,

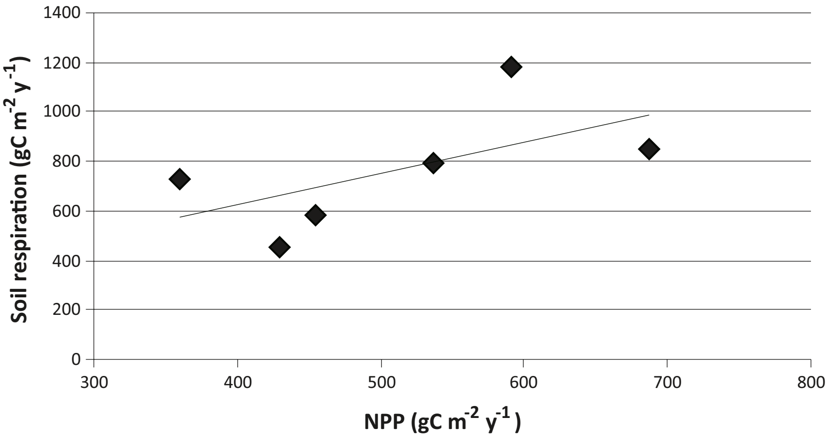


Figure 6-2. Soil respiration plotted against total NPP for the six localities. The NPP for locality G1 was adjusted by subtracting extra litter input due to a storm, see discussion above (Spearman r=0.77, p=0.07).

which were close to zero. /Lindroth et al. 2007/ presented estimates of eddy flux measurements in Norway spruce stands in northern Sweden for two consecutive years that were validated by field estimates (107 and 98–108, respectively /Berggren Kleja et al. 2007/). At a site in south-western Sweden, NEP was estimated to be 350 gC m^{-2} y^{-1} (160 gC m^{-2} y^{-1} accumulated in the SOC pool and 190 gC m^{-2} y^{-1} accumulated in the vegetation) in a 30-year-old Norway spruce forest /Persson and Nilsson (ed.) 2001/. /Pregitzer and Euskirchen 2004/ presented a range of –360 to 260 gC m^{-2} y^{1} for five boreal coniferous forests. The CoupModel estimated the NEP to be 82 and 84 gC m^{-2} y^{-1} for an old conifer forest in the Forsmark and the Laxemar-Simpevarp regions, respectively /Gustafsson et al. 2006/. The field estimates therefore seem to be in agreement with other investigations, based both on field estimates and model simulations.

6.3.3 Confidence and uncertainties

Variation in estimates

The standard deviations that were estimated and propagated through the calculations mainly represent spatial variation (see Table 6-4), due to the short measurement period. The large variation found for a number of properties on this rather small spatial scale indicates that a number of factors influence these properties on a small scale, such as soil properties, topography, water availability etc. The large standard deviations of the NEP estimates mainly stem from the large standard deviations in the soil respiration estimates, which suggests a high spatial variation on the scale measured. Interestingly, the lowest variation was found in the most even-aged forest stands with relatively low litter production in combination with the smallest SOC pool on a shallow soil layer.

In addition to the spatial variation, there are differences between years caused by variation in climatic variables such as temperature and precipitation. These differences could be explored with the field data used in this chapter. The temporal variation is further explored using model simulations in Chapter 7.

Confidence

NEP is calculated as the difference between large flows of carbon, namely NPP and heterotrophic respiration, and the errors associated with the estimations of these large fluxes must be regarded as potentially large. The largest contributions to NPP are tree litter production above and below ground, which are based on measurements performed in 2004–2006 and 2005, respectively. The turnover rate of fine root biomass was, however, only estimated at one locality in Forsmark and then extrapolated to the other localities using their specific fine root biomass.

Litterfall may be highly variable between years /Bray and Gorham 1964/, and the reliability of the methods estimating root turnover have been discussed (e.g. /Matamala et al. 2003, Trumbore and Gaudinski 2003/) and large differences have been found /Gill and Jackson 2000, Persson and Stadenberg 2007b/. Furthermore, soil respiration was only measured during one year at the site (2004–2005 in Laxemar-Simpevarp and 2005 in Forsmark), and /Euskirchen et al. 2003/ found an overall difference of 37% between two consecutive years in soil respiration, which was associated with changes in soil temperature for six vegetation types. Nevertheless, the estimates presented here, both single estimates of pools and fluxes and ecosystem emergent properties, are well within expected ranges.

6.3.4 Concluding remarks

We have used a simplified approach to estimate the accumulation of carbon in the SOC pool: carbon output subtracted from carbon input. Nevertheless, organic matter, with assimilated radionuclides, that is turned into litter would quickly be decomposed, creating an excess of radionuclides in comparison with carbon in the humus and upper mineral soil layer. The fate of this enrichment would depend on the strength of the chemical interaction with the solid phases of the different soil horizons, e.g. /Tipping 1996/.

Generally, the estimated pools and fluxes from the six localities in Forsmark and Laxemar-Simpevarp were in agreement those estimated in with similar studies, where available. However, some discrepancies were discovered. A high net emission from the soil in two localities suggests that either the underlying assumptions are invalid or that there may be a large variation between years in this property for the two localities. For the oak forest, the underlying assumption that heterotrophic respiration is 50% of soil respiration seems to be invalid, while the water-inundated alder shore forest may have a potential high between-year variation in NEE due to the location of the water table. Studies of boreal forest ecosystems are usually conducted in coniferous tree stands under dry to moist conditions. Here, data also included two different alder forest stands that are situated on water-logged soil during parts of the year. Few data for such vegetation types have been published previously. Overall, this exercise has generated a number of insights (discussed above) concerning the function of a subset of ecosystems at the two sites, even though the study only covers a short time period. Moreover, a site-specific database is now available for describing the pools and fluxes for a number of ecosystems that will be further explored on the regional scale in the next chapter.

7 Describing regional carbon balances using a dynamic vegetation model

7.1 Introduction

Estimating carbon balances at a regional level is a challenge that requires an understanding of the factors affecting the carbon processes and the features to be investigated. Available methodologies can be grouped into field estimates, remote sensing and ecosystem modelling. In a landscape containing a number of different vegetation types, ground-based measurements are expensive and labour-intensive and some features are difficult to measure. However, in Sweden forest inventory data are available on above-ground biomass for the fraction that is of economic interest. To estimate whole-tree carbon, “biomass expansion factors” are therefore necessary. These vary between different regions and are not very well known /Nabuurs et al. 1997/.

In satellite-based remote sensing, state and changes in the terrestrial biosphere are estimated by measuring reflected radiation in different electromagnetic bands. Several such products with estimates on different temporal and spatial scales are available and they are inexpensive compared to field measurements. Vegetation indices, such as ratios between different wavelength bands, are used in remote sensing for estimating, for example, leaf area index (LAI) or fraction of absorbed photosynthetically active radiation (FAPAR) /Chen and Cihlar 1995/. These characteristics can then be used to quantify and upscale physiological processes, such as photosynthesis, productivity and transpiration e.g. /Bonan 1993, Coble et al. 2001, Fassnach and Gower 1997, Jose and Gillespie 1997/. The complexity lies in the relationship between LAI or FAPAR and the carbon dynamics, since the relationship varies non-linearly due to differences in e.g. latitude, climate, biomes, species and season.

Dynamic ecosystem models can be used to estimate carbon cycle balances based on different input parameters such as climate, vegetation characteristics and soil properties. A dynamic vegetation model describes both physiological process and processes at the population and community level that affect vegetation dynamics. This approach also incorporates a temporal dimension, since carbon balances are highly influenced by stochastic disturbance regimes, climate changes and age of the stand. These influences are difficult, time-consuming and expensive to capture by field measurements and remote sensing. This chapter describes how the dynamic vegetation model, LPJ-GUESS, was used for estimating carbon balances for the two investigation areas. LPJ-GUESS has been subject to extensive validations of temporal and spatial variation in ecosystem carbon balance /Sitch et al. 2003, Heimann et al. 1998, Lucht et al. 2002, Morales et al. 2005/ and modelled species composition, biomass and species distributions /Badeck et al. 2001, Smith et al. 2001, Hickler et al. 2004/. In the Laxemar-Simpevarp investigation area, /Tagesson 2006c/ has also validated the model against soil respiration, tree biomass, net primary production (NPP) of grass ecosystems and the slow soil organic carbon (SOC) pool.

A new approach is to combine remote sensing with dynamic vegetation modelling. Satellite data show the spatial distribution of vegetation characteristics (e.g. LAI, FAPAR or vegetation structure), whereas the dynamic vegetation model estimates the relationship of these characters to physiological processes e.g. /Knorr et al. 2004/. The physiological processes can then be spatially extrapolated over the investigation areas.

In this chapter, the aim was to make a regional description of carbon balances using results by LPJ-GUESS for a number of different vegetation types dominating the Forsmark and Laxemar-Simpevarp investigation areas. Some areas (sea shore, wetlands and forested wetlands) were not included due to the extensive work required to adapt the model to these vegetation types. For these cases, field measurements as well as literature data are discussed in Chapter 4-1 and their parameterization is presented in Chapter 8. The model results cover the following vegetation types: young (25 y) and old (80 y) stands of Norway spruce (*Picea abies*), Scots pine (*Pinus sylvestris*), deciduous trees (oak (*Quercus robur*) and silver birch (*Betula pendula*)), mixed forests, dry pine on acid rocks, meadows and agricultural land.

The study was divided into four different parts. Firstly, the model was validated against field estimates to ensure that the parameterization of the model was suitable for the investigation areas and to confirm that estimated carbon balances are realistic in relation to measurements. Secondly, estimates of carbon balances for 2005 in the different vegetation types were made using the model. Thirdly, spatial variation in NPP was described by combining remote sensing and modelled NPP. And finally, temporal variation was described for a number of ecosystem properties for a 100-year forest cycle.

7.2 Materials and methods

7.2.1 Model description

LPJ (Lund Potsdam Jena)-GUESS (General Ecosystem Simulator) is a dynamic vegetation model that combines the dynamic ecological processes with the biogeochemical processes governing ecosystem carbon and water cycles /Sitch et al. 2003/. The biogeochemical processes include photosynthesis, respiration, tissue turnover and stomatal regulation, which control fluxes of C and H_2O between the different compartments of the ecosystem. The dynamic ecological processes are individual plant growth, plant resource competition, demographic processes and disturbances. A short report of the model is given here. For a more detailed description see /Sitch et al. 2003/ and /Smith et al. 2001/.

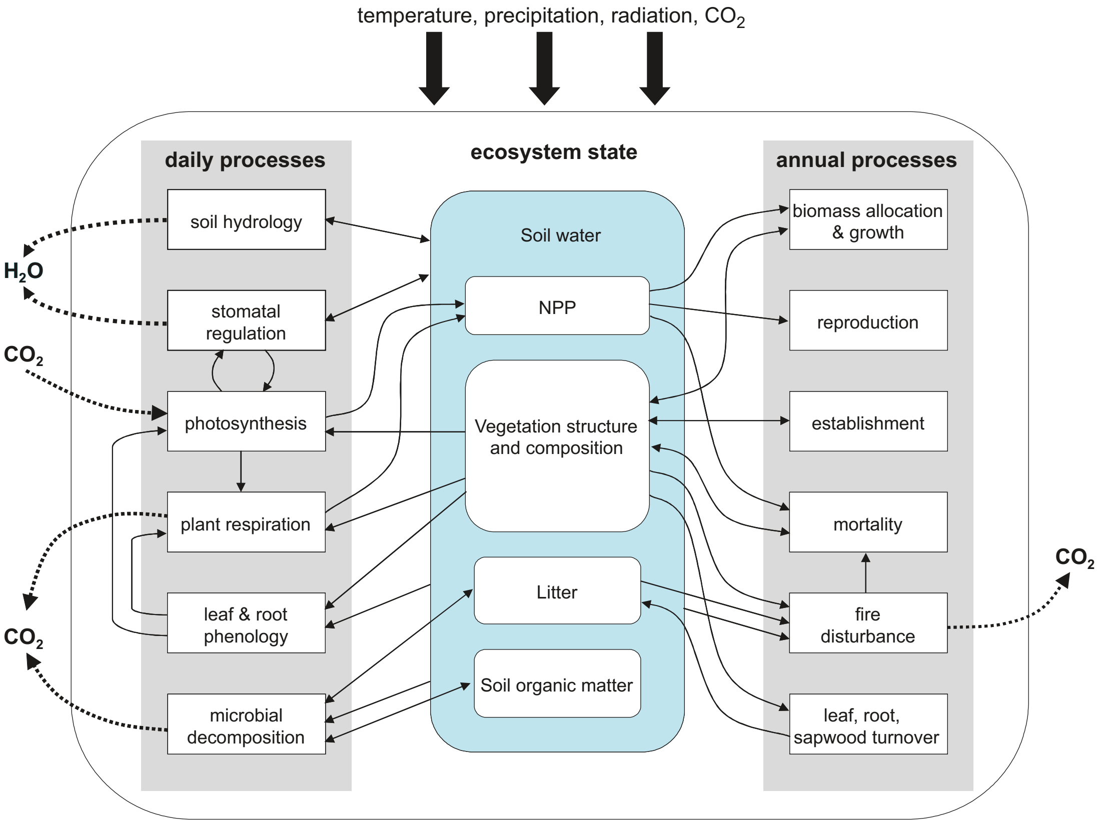


Figure 7-1. *Flowchart describing the main processes and ecosystem state variables, and their interactions in the dynamic vegetation model LPJ-GUESS.*

Dynamic vegetation models developed for simulations on a continental or global scale, so called DGVMs, use broadly defined plant functional types (PFTs) as basic biological units. Broadly defined, PFTs group the species within and among ecosystems with the same type of function and structure, and they have averaged parameters for the most part. These averaged parameters were based on the assumption of homogeneity in the vegetation and represents a necessary compromise between computational data and analytical demands for large-scale analyses of vegetation changes. On a smaller spatial scale, such as the landscape of the present investigation, DGVMs are too generalized and their spatial scale is too coarse. In LPJ-GUESS, more narrowly defined PFTs, individual species or cohorts (age classes of the same species) can be used. Herbaceous plants were also represented but not on an individual basis.

Abiotic parameters

The abiotic input parameters were latitude, soil texture, precipitation, temperature, insolation and atmospheric concentration of carbon dioxide. The ecosystem drivers – day length, growing season, photosynthetically active radiation (PAR), soil temperature, soil water, potential evapotranspiration, snow accumulation and snowmelt – were derived from these input parameters. The abiotic factors drove the model and thereby determined primary production, carbon cycling and vegetation dynamics.

Species properties

Each species simulated in the model has prescribed parameters that govern its specific response to environmental variation and ecosystem changes. Tree individuals were characterized by their allocation of carbon to the stem, roots, branches and leaves. This allocation gives the individual its characteristics of height, crown area, bole height and leaf area index (LAI). Light absorption and thereby competition between the individuals for light capture is dependent on LAI and the structure of the plant canopies. The properties of the species also determine their establishment rate and their susceptibility to changes in climate factors. Herbaceous PFTs were simulated as one aggregated PFT at ground level.

Net primary production

Gross Primary Production (GPP) of ecosystems is depending on the individual properties of the vegetation and the abiotic parameters that influence photosynthesis and stomatal conductance, which is in turn influenced by water uptake from the soil. Photosynthesis is dependent on the fraction of PAR assimilated by the woody individuals. Herbaceous PFTs assimilate the proportion of PAR that reaches ground level. Water balance is affected by evapotranspiration, soil hydrology and precipitation. Soil hydrology differs among 10 different soil texture types. Processes controlling evapotranspiration are dependent on the supply of soil water, water use by the plant and atmospheric water demand. Water supply can be a limiting factor for photosynthesis if atmospheric demand exceeds the water supply in the root zone of the plant.

Net Primary Production (NPP) is the proportion of GPP left for tissue production and reproduction after respiration resulting from plant use of carbohydrate energy (autotrophic respiration). Ten percent of the carbon from NPP is used for reproduction, while the rest is allocated to leaf, sapwood or root biomass. The tissue pools will be reduced due to mortality and tissue turnover.

Soil organic carbon and litter decomposition

Dead leaves, dead roots and all carbon from dead individuals were transferred to the above- and below-ground litter. The litter pool has a residence time of 2.86 years at 10ºC. When litter decomposes, seventy percent is respired to the atmosphere and the rest is transformed into soil organic carbon (SOC). Two SOC pools exist, a fast decomposing pool with a residence time of 33.3 years at 10ºC and a slowly decomposing pool with a residence time of 1,000 years at 10ºC. Abiotic factors that influence decomposition are soil and air temperature (exponential relationship) and soil moisture (linear relationship). Total heterotrophic respiration is the sum of respiration from the three pools.

Disturbances

Fire is the most important disturbance in forests and was the only disturbance modelled explicitly in the model. The fire regime was set to be dependent on fire fuel and litter moisture in the ecosystems. Fire cannot spread below a minimum fuel load and above a threshold value of moisture content. Other disturbances, e.g. storms, droughts, pests, diseases and clear-cutting, can be set to have average return times. When there is a disturbance, all aboveground biomass in the ecosystem is fully consumed and released back to the atmosphere.

7.2.2 Input parameters

Model settings

The parameters of the model were chosen in order to correspond to the conditions at both sites. Following is a description of the parameterization and modifications done with the model.

The model was set up to run in cohort mode, where age classes of the same species were distinguished. The Beer-Lambert coefficient was set at 0.45, estimated by /Lagergren et al. 2005/ for the Norunda research area not far from Forsmark. The proportion of PAR that is lost due to absorption by non-photosynthetic structures, such as stem and branches, was set at 0.4. Clear-cutting and re-establishment of a forest was prescribed in the same year as the forest was planted according to the forest management plan (cf. below). When the forests were clear-cut, it was assumed that 30% of the woody biomass entered the litter pool and the rest was removed as timber. All leaves and fine roots of the clear-cut forests were transferred to litter. The model had a spin-up period of 300 years to establish vegetation and soil carbon pools at equilibrium with the long-term climate. During this spin-up period, the first 30 years of the climate dataset and the first year of the carbon dioxide dataset were used.

The model was set to have a fire disturbance regime as well as general patch destroying disturbances with an average return time of 100 years, considering an average for natural disturbances in Sweden /Zackrisson 1977, Bradshaw and Zackrisson 1990/. Simulations were made for 100 patches with an area of 0.1 ha each. For the outputs, an average value of these 100 patches was calculated.

Output variables from the model were annual NPP, biomass and leaf area index both as ecosystem totals and for individual species. Ecosystem level output variables used were GPP, carbon fluxes to vegetation (NPP), carbon fluxes caused by fire, soil respiration and Net Ecosystem Exchange (NEE, i.e. the sum of all above fluxes). Additional ecosystem level output variables were FAPAR, autotrophic respiration by leaves, sapwood, roots, growth respiration, litter pools of root, leaf, wood and reproduction C and slow and fast SOC pools. Additional output variables (as ecosystem totals and for individual species) were stocks of leaves, sapwood, heartwood and fine roots.

Climate

Due to a lack of long time series from the specific sites, climate parameters were obtained from several different meteorological stations. Climate data were collected from NORDKLIM, NORDisk KLIMasamarbeid /SMHI 2003/, and the meteorological stations in Lövsta, Örskär, Oskarshamn, Gladhammar, Högmasten and Äspö /Johansson et al. 2005, Larsson-McCann et al. 2002a, Lärke et al. 2005/. The stations in the surroundings of Forsmark were Uppsala, Stockholm and Svenska högarna and the stations in the surroundings of Laxemar-Simpevarp were Krokshult, Växjö, Kalmar and the north cape of Öland /SMHI 2003/.

Temperature

Data recorded in Örskär situated in the Forsmark investigation area were used for the years 1961–2004 /Larsson-McCann et al. 2002b/. To get values between 1901 and 1960, a reference temperature was calculated with the dataset from Örskär and the NORDKLIM climate stations

Uppsala, Stockholm and Svenska högarna /SMHI 2003/. Reference values (Tr) can be calculated by /Alexandersson and Moberg 1997/:

$$T_r = \Sigma^k_{j=1} (\rho_j{}^2 (X_{ji} - X_{aj} + Y_a)) (\Sigma^k_{j=1} (\rho_j{}^2))^{-1} \qquad \text{(Eq. 7-1)}$$

where ρj is the Pearson correlation coefficient between the climate station in Örskär and the other climate stations (j) during the period 1961–2000, X_{ji} is the temperature at the other climate station for the year and month (i), X_{aj} is the average temperature for each month 1961–2000 at the climate station j and Y_a is the average temperature for each month 1961–2000 at the climate station in Örskär. For 2005–2006 measurements from Högmasten situated in the Forsmark investigation area were used /Larsson-McCann et al. 2002b, SMHI 2003, Johansson et al. 2005/.

For Laxemar-Simpevarp, measurements from Oskarshamn situated 25 km south of the Laxemar-Simpevarp investigation area were used for the years 1961–2000. To get values between 1901 and 1960, a reference temperature (Eq. 7-1) was calculated using the datasets from Oskarshamn, Växjö, north cape of Öland and Kalmar /SMHI 2003/. Measurements from the Äspö climate station were used for 2004 to 2006 /Lärke et al. 2005/.

Precipitation

Precipitation data from 1961 to 2004 were obtained from Lövsta /Larsson-McCann et al. 2002b/ for the Forsmark simulations. No data were available for 1901–1960, and reference values were therefore calculated for the period 1901–1960 with data from the surrounding NORDKLIM climate stations in Stockholm, Uppsala and Svenska högarna, where the precipitation was measured between 1890 and 2000 /SMHI 2003/. Reference values (Pr) for precipitation can be calculated by /Alexandersson and Moberg 1997/:

$$P_r = \Sigma^k_{j=1} (\rho_j{}^2 (X_{ji}\, Y_a\, X_{aj}^{-1})) (\Sigma^k_{j=1} (\rho_j{}^2))^{-1} \qquad \text{(Eq. 7-2)}$$

where ρ_j is the Pearson correlation coefficient between the climate station in Lövsta and the other climate station (j) during the period 1960–2000, X_{ji} is precipitation at the other climate station for the year and month (i), X_{aj} is the average precipitation for each month 1960–2000 at the climate station j and Y_a is the average precipitation for each month 1960–2000 at the climate station in Lövsta.

Measurements of precipitation started at Högmasten in the Forsmark investigation area in September 2003 /Johansson et al. 2005/, and data from Högmasten in the Forsmark investigation area were used for the years 2005–2006. Measured precipitation is not true precipitation due to different factors such as wind, topography, evaporation and adhesion; all precipitation data were therefore corrected according /Alexandersson 2003/.

Precipitation data for the period 1912–2003 from Krokshult, situated about 25 kilometres west of Simpevarp were used for Laxemar-Simpevarp /SMHI 2003/. Reference precipitation was calculated with equation 7-2 for 1901–1912 using the data from Krokshult and the surrounding climate stations in Växjö, Kalmar and the north cape of Öland /SMHI 2003/. For 2004 to 2006, data were taken from the Äspö climate station /Lärke et al. 2005/. All Laxemar-Simpevarp precipitation data were corrected according to /Alexandersson 2003/.

Solar radiation

For the Forsmark simulations, cloudiness from 1901–2001 was taken from the climate station in Stockholm /SMHI 2003/. For 2004–2006, solar radiation was measured in W m^{-2} at Högmasten in the Forsmark investigation area /Johansson et al. 2005/. Average monthly radiation was calculated using daytime data, i.e. radiation greater than 10 W m^{-2} (Smith, pers. comm.). For 2002 and 2003, no measured data could be found in the surrounding areas and therefore linear regressions between cloudiness and precipitation 1901–2001 were done for each month. The regressions were used on the precipitation data set to estimate cloudiness for each month in 2002 and 2003.

Cloudiness data for 1901–2000 were taken from Växjö for the Laxemar-Simpevarp simulations /SMHI 2003/. Solar radiation was measured in W m^{-2} at the climate station in Gladhammar 2003 and at Äspö for the period 2004 to 2006 /Lärke et al. 2005/. Average monthly radiation was calculated using data greater than 10 W m^{-2} for 2003 to 2006. For 2001 and 2002, no measured data could be found and therefore linear regressions with cloudiness against precipitation 1901–2000 were done for each month. The regressions were used on the precipitation data set for each month 2001 and 2002 to estimate cloudiness.

Carbon dioxide

An annual data set for the period from 1901 to 1998 for atmospheric concentration of carbon dioxide was taken from the Carbon Cycle Model Linkage Project /McGuire et al. 2001/. For the missing years 1999–2006, data was taken from a dataset from Mauna Loa /Tans 2006/.

Soil characteristics

Soils in the Forsmark investigation area are characterized by low-lying, young (less than 1,500 years) land formed by the sea /Lundin et al. 2004/. Sea waves have redistributed the material so that upland parts have coarser material, thin soils and bare bedrock, whereas the low-lying areas have a fairly high clay content in the sediments /Lundin et al. 2004/. Gleysol and Regosol are dominant soil types in the Forsmark area, which have coarse-textured till. These soils mainly have coniferous forests growing on them /Lundin et al. 2004/. Leptosols with shallow soil depths at upslope locations are also common /Lundin et al. 2004/. Pine and spruce forests dominate the tree layer. Regosol and Gleysol soil types dominate on arable land and pastures, and these soils can be found in clayey till. Two different soil types were chosen for Forsmark: medium-coarse soil types for the forest simulations and finer soil textures for the arable land and pastures. In the model, soil was divided into two different soil layers: an upper and a lower. Normally, the soil depth was 1,000 mm and the boundary between the layers was at a depth of 500 mm. For the Leptosol areas, the model was modified to have a soil depth of 250 mm and the boundary between the upper and lower soil layer was set at 125 mm.

The Laxemar-Simpevarp investigation area contains a wide variation of soil textures, mainly due to differing topography /Lundin et al. 2005a/. The most common soil type is Podzol/Regosol with quite coarse-grained sandy and sandy-silty textured till and sorted sediments, and in these areas mainly forests occur /Lundin et al. 2005a/. At the most upslope parts, the most common soil type is Leptosols, and in these areas the soil cover is rather thin (0.0–0.3 m). The soil texture mainly consists of fairly coarse sandy and sandy silty till /Lundin et al. 2005a/. These areas are mainly covered by pine forest. In low-lying flat areas, the most frequent soil type is Umbrisol and the soil materials are mainly silt, clay and gyttja. These areas have been used as arable land and pastures /Lundin et al. 2005a/. The same soil types were chosen for Laxemar-Simpevarp as for Forsmark: medium-coarse soil types for the forest simulations and finer soil textures for the arable land and pastures. The soil depth was set at 1,000 mm and the boundary between the layers was at a depth of 500 mm. For the Leptosol areas, soil depth was set at 300 mm and the boundary between the layers was set at 150 mm.

Vegetation

A vegetation map derived from remote sensing of Forsmark and Laxemar-Simpevarp was used in order to identify the range of different vegetation types, (Figures 3-4 and 3-8 /Boresjö Bronge and Wester 2003/). A selection was made from this list of vegetation types in order to represent the most abundant and important vegetation types in terms of being potential sinks for organic matter (wetlands) and potential human food sources (arable land, pastures).

In the vegetation map, old and young conifer forests can be distinguished based on the spectral characteristics of a stand. These spectral characteristics were also related to site quality but seem to be equivalent to forest age when the stand is in the cutting class “thinning forest” or older /Boresjö 1989/ (3x and 4x in Table 7-1). The spectral characteristics attained from the SPOT satellite were from 1999. The age distribution within cutting classes at the time of interpretation of the spectral characteristics (1999) was obtained from the forest management plan (In Swedish "Skogsbruksplanen"), which covers a substantial part of the regional model area of Forsmark. For Forsmark it is feasible to suggest that the median forest age for young forest in 2005 is approximately 25 years, see Table 7-1. If a similar method is used, the median age for old forest would be overestimated, since old forests are continuously being cut down, so their median age was at to 80 years. Deciduous forest age was estimated for the cutting class "thinning forest" or older separately, using 19 stands, which gave a similar age as for the older forest.

Data on cutting classes and ages in Laxemar-Simpevarp were not available. The forested area is divided up among a large number of private landowners, which makes it difficult to get an overall picture of this information. The management situation was assumed to be similar in Laxemar-Simpevarp as in Forsmark and the ages of the forests in the different thinning classes should consequently approximate those in Forsmark.

In the present study the model was configured to simulate major forest tree species, i.e. Norway spruce (*Picea abies*), Scots pine (*Pinus sylvestris*), silver birch (*Betula pendula*) and oak (*Quercus robur*). Parameters for C_3 grass were used for the field layer. Young stands were set to be clear-cut in 1980 and old stands were set to be clear-cut in 1925. The clear-cuts were set to be harvested in 2002 and clear-cuts with birch were harvested in 1990. The vegetation types and the species included in the simulations are presented in table 7-2. Output data for 2005 were used as results.

The parameterization of the vegetation follows previous studies by /Hickler et al. 2004/ and /Koca et al. 2006/. Specific parameters for PFTs were used for the parameters concerning physiology and life history of the species, i.e. different values were given to trees versus grasses, angiosperms versus gymnosperms, boreal versus temperate, and to shade-tolerant versus intolerant species /Fulton 1991, Haxeltine and Prentice 1996, Vogt et al. 1996, Smith et al. 2001, Li et al. 2003, Sitch et al. 2003, Gerten et al. 2004, Hickler et al. 2004, Koca et al. 2006/. Longevity and bioclimatic limits for survival and establishment were given specific values for each species /Skre 1972, Prentice and Helmisaari 1991, Bugmann 1994, Sykes et al. 1996, Bradshaw et al. 2000, Koca et al. 2006/. All crop root biomass was transformed to root litter, since no roots survive until the next year because the fields are ploughed in the autumn. In the crop simulations, 66% of the leaf biomass was removed from the field and 33% remained as litter (Olsson, HIR Malmöhus pers. comm.). It was also assumed that crop root biomass is 19% of the total biomass /Andren et al. 1990/, and for the other parameters, crop had exactly the same values as grass. All parameters are given in table 7-3.

Table 7-1. The age of the cutting classes that correspond to young and old forest in the vegetation map of the Forsmark area. The statistics are taken from Sveaskog's management plan (in Swedish skogsbruksplan), which was updated in 1999–2000 and covers a substantial part of the regional model area.

Cutting class	Mean age	Median age	Min. age	Max. age
2x	19	18	6	37
3x and 4x	73	78	24	166

Table 7-2. Major ecosystems in the investigation areas as identified in the vegetation map by /Boresjö Bronge and Wester 2003/, and the species included in the different simulations.

Ecosystem	Species included in simulations
Young Norway spruce	Norway spruce, grass
Old Norway spruce	Norway spruce, grass
Young Scots pine	Scots pine, grass
Old Scots pine	Scots pine, grass
Scots pine on bedrock	Scots pine, grass
Mixed forest	Norway spruce, Scots pine, Silver birch, oak, grass
Old deciduous forest	Silver birch, oak, grass
Clear cut	Silver birch, grass
Clear-cut with birch (young deciduous)	Silver birch, grass
Pasture	Grass
Arable land	Crop

Table 7-3. Species properties for the modelled vegetation types.

Parameters	Details			
Growth form	**Tree**	**Grass**	**Crop**	
min. PAR flux for establishment (MJ m^{-2} day^{-1})	–	2.5	2.5	
fraction of roots in upper/lower soil layer	0.67/0.33	0.9/0.1	0.9/0.1	
fine root turnover (y^{-1})	0.7	0.7	1	
leaf/root (all roots?BG)	1	0.5	5.26	
Tree type	**Gymnosperms**	**Angiosperms**		
leaf phenology	Evergreen	Summergreen		
min. canopy conductance	0.3	0.5		
leaf area/sapwood area (m^2 cm^{-2})	2	3		
leaf turnover (y^{-1})	0.33	1		
sapwood conversion (y^{-1})	0.05	0.1		
specific leaf area (cm^2 $(gC)^{-1}$)	220	410		
canopy interception parameter	0.06	0.02		
Climate zone	**Boreal**	**Temperate**		
optimal temperature range for photosynthesis	10–25	15–25		
Shade tolerance class	**Intolerant**	**Intermediate**	**Tolerant**	
growth efficiency threshold for stress mortality (kgC m^{-2} y^{-1})	0.12	0.1	0.0001	
max. establishment (saplings ha^{-1} y^{-1})	2,500	1,875	1,250	
recruitment shape parameter	10	6	3	
Tree taxon	**Spruce**	**Pine**	**Silver birch**	**Oak**
type	gymnosperm	gymnosperm	angiosperm	angiosperm
climate zone	boreal	boreal	boreal	temperate
shade tolerance	tolerant	intermediate	intolerant	intermediate
max. non-stressed longevity (y)	900	760	300	1,060
min. Tc for survival (°C)	–	–	–	–18
min. Tc for reproduction (°C)	–	–	–	–16
max. Tc for reproduction (°C)	–2	–1	–	–
min. GDD_5 for reproduction[1]	600	500	150	1,100

[1] Accumulated temperature for annual growing degree days on 5°C base; $GDD_5=\sum_d (T_d–5.0)$; T_d=mean temperature of Julian day.

7.2.3 Spatial variation in NPP

During 2005, LAI was estimated optically using LAI-2000, TRAC and the gap fraction method in representative forest stands at both Laxemar-Simpevarp and Forsmark. LAI was also extrapolated over both investigation areas based on normalized difference vegetation index (NDVI) images (see Section 4.1.3) /Tagesson 2006a/.

NPP was linked to LAI using the simple light use efficiency model /Ruimy et al. 1994/. The concept is to estimate NPP from FAPAR and a light use efficiency constant, ε

$$NPP = \varepsilon \, PAR \, FAPAR \qquad \text{(Eq. 7-3)}$$

where ε is the light use efficiency constant. FAPAR is highly linked to NPP since plants gain no benefit from harvesting more light than they have resources to use, and by combining this information with a variant of the Beer Lambert law (Eq. 7-4), NPP can be estimated.

$$FAPAR = 1 - \exp(-k \, LAI) \qquad \text{(Eq. 7-4)}$$

where FAPAR is the fraction of the PAR that is absorbed and *k* is the light extinction coefficient. The light extinction coefficient was estimated to be 0.45 for a mixed middle-aged coniferous forest in Norunda, not far from Forsmark /Lagergren et al. 2005/.

$$NPP = (\varepsilon \, PAR) - (\varepsilon \, PAR) \exp(-0.45 \, LAI) \qquad \text{(Eq. 7-5)}$$

ε PAR can be estimated from the model by dividing NPP by FAPAR. For each forest type in table 7-2 identified in the vegetation map by /Boresjö Bronge and Wester 2003/, this fraction and equation 7-5 were used on the LAI image to calculate NPP for both investigation areas. Average values and standard deviation of NPP were calculated for the different vegetation types (table 7-2) in a GIS. This enabled us to describe the spatial variation in NPP caused by differences in nutrients, microclimate and other natural variation that exists within the investigation areas that is not possible to estimate directly by means of a mechanistic model based on climatic variables and input parameters only. From now on, NPP estimated directly from the model will be referred to as "model-estimated NPP", while the estimates based on the light-use efficiency model are referred to as "LAI-based NPP".

7.2.4 Temporal variation of carbon balances during a forest cycle

For the forested areas, simulations were performed to describe variation in pools and fluxes during a 400-year period. Temporal variation in carbon balances is difficult to estimate in the field, due to the extensive work required for ground-based estimates. The main components investigated were NPP, litterfall, heterotrophic soil respiration and accumulation of carbon in the soil organic carbon pool. All species were included to estimate vegetation dynamics after a clear-cut. After the spin-up period, the forests were clear-cut in 1901 and the 100 years of climate data were repeated 4 times in order to cover the whole simulation period.

A forest cycle lasts on average 100 years (Sveaskog AB pers. comm.). The forests in the investigation areas are managed, and to get estimates for these forests, descriptive statistics were also calculated for the first 100-year period of the simulations. Maximum values were calculated from the 400-year perspective, approximating a long period of tree continuity without major disturbances.

7.2.5 Temporal variation in carbon balances for agricultural areas

NPP, crop yield and the accumulation of organic matter in soils are the most important factors in the agricultural areas for a risk assessment of the investigation areas. The harvested yield was assumed to be 0.66 of the leaf biomass (Olsson, HIR Malmöhus pers. comm.), which was removed each year. In the simulations of the agricultural areas, the crop was the only species. Mean values and standard deviation of NPP, crop yield and the accumulation of organic matter were calculated for the period 1901–2000.

7.2.6 Evaluation of model results

Field-estimated data

LAI, soil respiration and stem increment were estimated in the field and compared with the model estimates. In 2005, LAI was estimated with LAI-2000, TRAC and the gap fraction method in representative forest stands in Laxemar-Simpevarp and Forsmark /Tagesson 2006a/. LAI was also extrapolated using NDVI images over both investigation areas /Tagesson 2006a/, see Section 4.1.3.

Soil respiration was estimated by means of the closed-chamber technique for six different ecosystems in Laxemar-Simpevarp in March 2004–March 2005 /Tagesson and Lindroth 2007/. In 2005 and 2006, it was also estimated in seven different ecosystems in Forsmark and four additional ecosystems in Laxemar-Simpevarp /Tagesson 2007/. See Section 4.2.4 and table 4-46/.

Site indices were estimated using the methods and height development curves in (Hägglund and Lundmark 1987a and b/ with age and height estimated in the field in representative forest stands in the investigation area /Tagesson 2006a/. The site characteristics were based on /Lundin et al. 2004 and 2005a/ and /Löfgren 2005/. Site indices could not be estimated using the height development curves at two sites, containing deciduous forest, since the forest stands were not even-aged or homogeneous. The site characteristic tables for pine were then used /Hägglund and Lundmark 1987ab/, since no tables exists for deciduous stands and pine is a common vegetation type in the areas. Site indices were converted to site quality classes using tables in /Hägglund and Lundmark 1987a/. The site quality class of a site describes the potential stem increment of the trees averaged over a forest cycle.

Evaluation of model results

Model-estimated LAI 2005 was compared with both field-estimated LAI and average NDVI-estimated LAI for the different simulations. Linear regressions were calculated and the residuals were checked against a normal distribution using a Kolmogorov-Smirnov test. This was done with all datasets before performing Pearson correlations. All statistical analysis was done in SPSS 12.0.1, and results were regarded as significant if $p< 0.05$.

The same procedure was used for model-estimated soil respiration compared with ground-based-estimated soil respiration. The model-estimated soil respiration was compared with the ground-based estimates using the same year in the model output as with the field estimates. To get as close to field estimates of soil respiration as possible, estimates of heterotrophic respiration and root respiration were combined from model results. A problem was that respiration from the field layer and larger roots are not included in this estimate. For pastures and agricultural areas, soil respiration and total vegetation respiration were added. A Pearson correlation was performed between model-estimated and field-estimated soil respiration.

The stem increment was estimated in 2005 and compared with model-estimated and LAI-based NPP for the same years. To compare field-estimated stem increment with model-estimated NPP, NPP was converted to stem increment. The method using conversion factors from NPP to stem increment was taken from /Nabuurs et al. 2003/. The total standing tree volume 1996–2000 for Kronoberg County (coniferous 99,300,000 m^3, deciduous 19,200,000 m^3) and Uppsala County (coniferous 51,300,000 m^3, deciduous 11,300,000 m^3) obtained from /SLU 2001/ was divided into its different compartments stem, branches, roots and foliage in fractions of 0.55, 0.24, 0.17 and 0.04, respectively /Nabuurs et al. 2003/. The turnover rates were assumed to be 0.0024, 0.02, 0.03 and 0.5 per year, respectively, for the same compartments /Nabuurs et al. 2003/. Total litter production in the counties was estimated based on these parameters and the different tree biomass compartments. The mean stem volume increment for Kronoberg (coniferous 3,690,000 m^3y^{-1}; deciduous 760,000 m^3y^{-1}) and Uppsala (coniferous 1,900,000 m^3y^{-1}; deciduous 470,000 m^3y^-1) counties between 1996 and 2000 were provided by /SLU 2001/.

Total NPP for the counties was calculated by summing total litter production and stem increment. Average conversion factors for transferring NPP to stem increment was estimated for coniferous forests in both Kronoberg and Uppsala county (0.00176 $m^3\,kgC^{-1}$), and for deciduous forests of Kronoberg and Uppsala county (0.00183 $m^3\,kgC^{-1}$ and 0.00189 $m^3\,kgC^{-1}$), assuming a wood carbon density of 225 kgC m^{-3} /Jarvis et al. 2001/. Both model-estimated and LAI-based NPP were transformed to stem increment using these conversion factors and evaluated with a Pearson correlation against field-estimated stem increment.

7.3 Results

7.3.1 Evaluation of the dynamic vegetation model

Leaf Area Index

On average, the model-estimated LAIs were acceptable compared with field estimates. The average field-estimated LAI was 3.14±0.92, while for the same ecosystems the model estimated it at 3.07±0.43. The Pearson correlation between modelled LAI and field LAI for each stand was not significant. However, when the model was compared with NDVI-estimated LAI instead, there was a correlation (r=0.779, df=12 p=0.001). Average NDVI-estimated LAI was 3.54±0.84, whereas model-estimated LAI was 3.21±0.50. See Figure 7-2.

Soil respiration

Average model-estimated soil respiration was 534±137 gC m^{-2} y^{-1} while field estimates were 823±230 gC m^{-2} y^{-1}. The model was closer to the field estimates in Forsmark (model 543, field 657) than in Laxemar-Simpevarp, where the estimates were lower (model 529, field 928). There was no correlation between modelled and field estimates of soil respiration (Figure 7-3).

NPP

The average stem increment in the field was estimated to be 5,911 ± 2,986 m^3 ha^{-1} y^{-1} (120 gC m^{-2} y^{-1}) whereas model-estimated NPP converted to stem increment was 8,880±0,997 m^3 ha^{-1} y^{-1} (174 gC m^{-2} y^{-1}). LAI-based NPP converted to stem increment increased the average value to 9,597±1,034 m^3 ha^{-1} y^{-1}. There was no correlation between field-estimated and model-estimated stem increment, whereas there was a correlation between field-estimated and LAI-based stem increment (r=0.661, df=12, p=0.014) Figure 7-4.

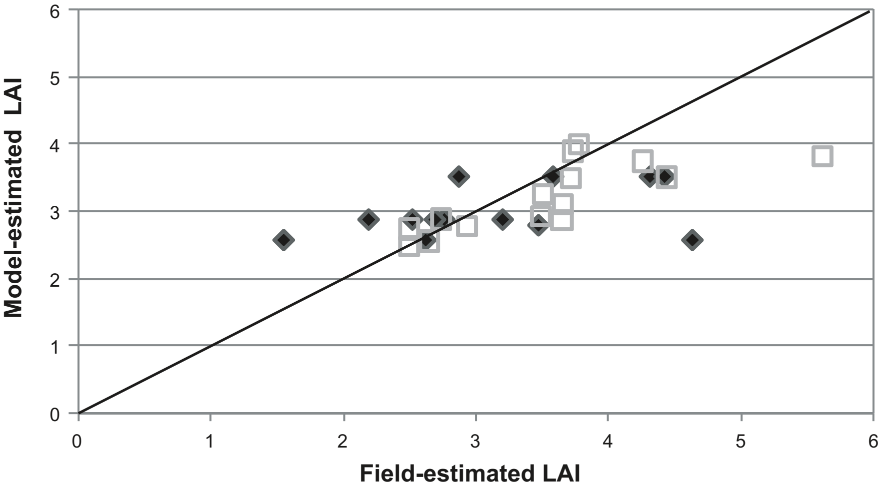


Figure 7-2. *Model-estimated LAI compared with field-estimated LAI. Filled symbols are measured LAI values in local stands and open symbols are average NDVI-estimated LAI values for young and old pine, young and old spruce, old deciduous stands, old dry pine on acid rock, old mixed forest stands in both Forsmark and Laxemar-Simpevarp and clear-cut birch in Forsmark.*

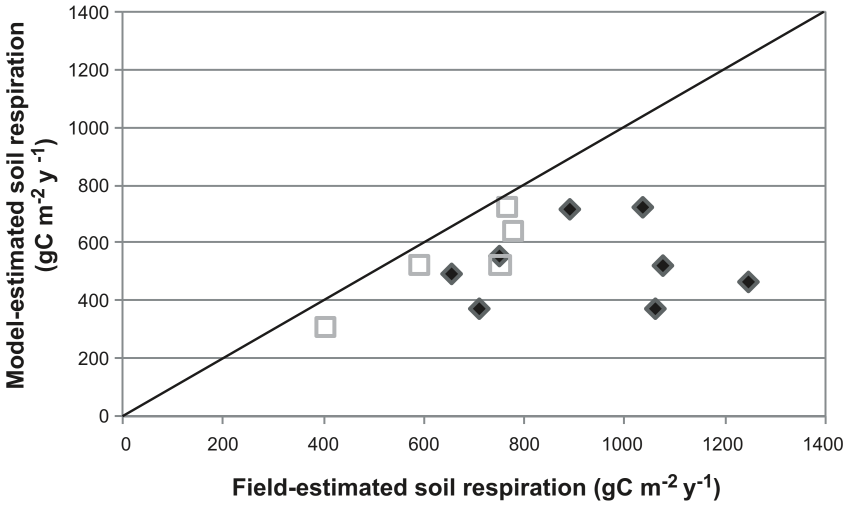


Figure 7-3. *Modelled soil respiration for both Forsmark and Laxemar-Simpevarp versus field-estimated soil respiration for the local stands. Open symbols are Forsmark and filled symbols are Laxemar-Simpevarp. The line shows the 1:1 relationship.*

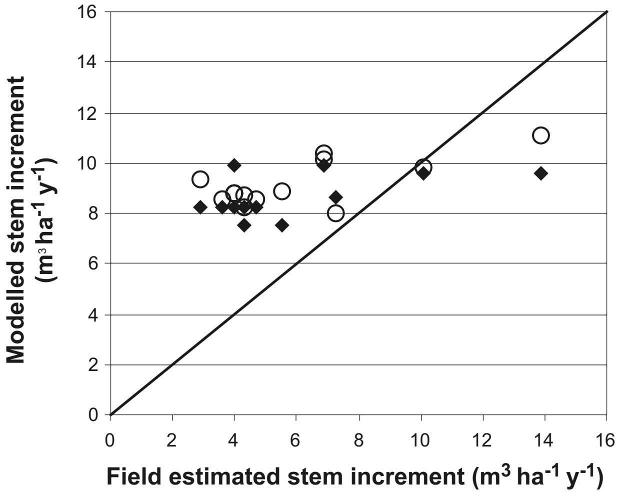


Figure 7-4. *Model-estimated stem increment versus field-estimated stem increment for the local stands in Forsmark and Laxemar-Simpevarp. Filled dots are model-estimated stem increment versus field-estimated, whereas the circles are LAI-based stem increment versus field-estimated. The line shows the 1:1 relationship.*

Carbon balances of ecosystems in the Forsmark and Laxemar-Simpevarp investigation areas

Modelled carbon pools and fluxes for the different ecosystems in Table 7-2 are presented in Tables 7-4 and 7-5. The results show that all ecosystems in both Forsmark and Laxemar-Simpevarp were net sinks for carbon during 2005. Most carbon was accumulated in the vegetation, whereas the SOC pools were sources of carbon for most ecosystems in both Forsmark and Laxemar-Simpevarp.

Table 7-4. Table of pools and fluxes predicted by LPJ-GUESS characterizing different vegetation types in Forsmark. Pools are in gC m^{-2} and fluxes are in gC m^{-2} y^{-1}. A positive value represents an accumulation of carbon in the soil whereas a negative value represents a loss of carbon to the atmosphere.

Func layer	Pools/fluxes		Spruce25	Spruce80	Pine25	Pine80	Dry pine	Deciduous	Mixed	Clear-cut	C-c birch	Pasture	Agri
Tree layer	biomass	Wood	3,997	8,702	4,201	8,201	8,458	6,379	7,017	87	1,821	–	–
		Green	222	194	216	173	181	61	128	9	67	–	–
		Fine roots	222	194	216	173	182	61	128	9	67	–	–
	NPP		628	564	617	570	586	456	505	70	497	–	–
Field layer	Biomass	Green	13	14	12	7	2	3	11	146	15	176	361
		Roots	26	28	25	15	4	6	22	291	29	353	69
	NPP		37	39	33	17	4	6	29	428	38	477	584
Soil	SOC	Litter pool	2,090	2,658	1,997	2,305	2,281	1,707	2,118	3,597	1,914	2,124	1,782
		SOC	11,840	11,397	11,373	11,254	11,040	7,923	1,836	12,211	11,516	9,097	7,055
	Heterotrophic soil respiration		–355	–404	–361	–398	–452	–298	–358	–571	–347	–327	–439
Total	NEE		280	230	276	190	140	165	183	–76	204	150	145
	GPP		1,396	1,304	1,330	1,225	1,248	856	1,077	866	969	916	942
	NPP tot		664	603	650	587	591	461	534	498	535	477	584
	Litter production		428	594	301	337	326	284	370	242	394	444	193
	Net accumulation veg		177	–7	306	246	261	172	158	245	134	33	0
	Net accumulation litter		133	238	7	54	–119	5	37	–385	110	117	0
	Net accumulation soil		–30	–1	–26	–6	–2	–2	–12	64	–40	0	0

Table 7-5. Table of pools and fluxes predicted by LPJ-GUESS characterizing different vegetation types in Laxemar-Simpevarp. Pools are in gC m^{-2} and fluxes are in gC m^{-2} y^{-1}. A positive value represents an accumulation of carbon in the soil whereas a negative value represents a loss of carbon to the atmosphere.

Func. layer	Pools/fluxes		Spruce25	Spruce80	Pine25	Pine80	Dry pine	Deciduous	Mixed	Clear-cut	C-c birch	Pasture	Agri
Tree layer	biomass	Wood	3,912	8,340	4,377	8,163	7,974	5,958	7,339	099	1,856	–	–
		Green	212	195	208	159	155	62	119	10	62	–	–
		Fine roots	213	196	208	160	157	63	120	10	62	–	–
	NPP		566	543	561	466	466	410	459	74	444	–	–
Field layer	Biomass	Green	10	9	8	9	8	8	7	120	8	288	288
		Roots	20	19	15	18	16	16	15	246	16	281	57
	NPP		25	25	25	25	19	25	25	25	25	371	446
Soil	SOC	Litter pool	1,923	2,344	1,826	2,954	2,566	1,884	2,286	3,825	1,699	2,102	1,754
		SOC	12,612	12,378	12,403	12,646	1,713	9,965	11,584	11,270	11,312	1,589	8,380
	Heterotrophic soil respiration		–297	–346	–281	–375	–459	–290	–320	–532	–275	–308	–389
Total	NEE		277	–194	318	100	43	39	32	–123	156	7	63
	GPP		1.271	1,263	1,277	1,153	175	855	1,033	792	70	773	750
	NPP tot		591	568	580	487	484	430	478	420	463	371	446
	Litter production		354	346	371	744	592	312	448	257	360	379	446
	Net accumulation veg		210	–193	196	–340	–119	10	–101	148	50	–8	0
	Net accumulation litter		102	8	163	452	160	41	146	–352	142	88	0
	Net accumulation soil		–35	–9	–41	–2	2	–12	–13	81	–36	–10	0

__Figure 7-5.__ Spatial distribution of NPP (kgC m^2 y^{-1}) in forested areas of a) Forsmark and b) Laxemar-Simpevarp.

Spatial variation in NPP

NPP was on average 567±130 gC m^2 y^{-1}for the forested areas in Forsmark and 530±77 gC m^2 y^{-1} in Laxemar-Simpevarp 2005. NPP and LAI distribution in the different ecosystems is shown in Table 7-6 for Forsmark and Laxemar-Simpevarp. The spatial distribution of NPP over the investigation areas can also be seen in Figure 7-6.

Table 7-6 Descriptive statistics of the spatial distribution of NPP (gC m^2 y^{-1}) and LAI for the different ecosystem types in Forsmark and Laxemar-Simpevarp.

Ecosystem	Forsmark NPP mean±sd	max	Forsmark LAI mean±sd	Laxemar-Simpevarp NPP mean±sd	max	Laxemar-Simpevarp LAI mean±sd
young spruce	627±130	710	3.72±0.92	659±20	706	5.61±0.70
old spruce	609±86	677	3.71±0.57	615±24	691	4.43±0.55
young pine	615±127	703	3.66±0.89	597±49	702	4.26±1.01
old pine	615±110	694	3.64±0.72	538±36	649	3.66±0.53
dry pine	582±138	683	3.42±0.88	492±38	645	2.93±0.45
deciduous	416±113	608	2.25±0.83	416±109	613	2.63±0.93
mixed	555±101	650	3.37±0.71	461±26	630	2.71±0.37
clear cut birch	457±77	668	2.15±0.59	–	–	–

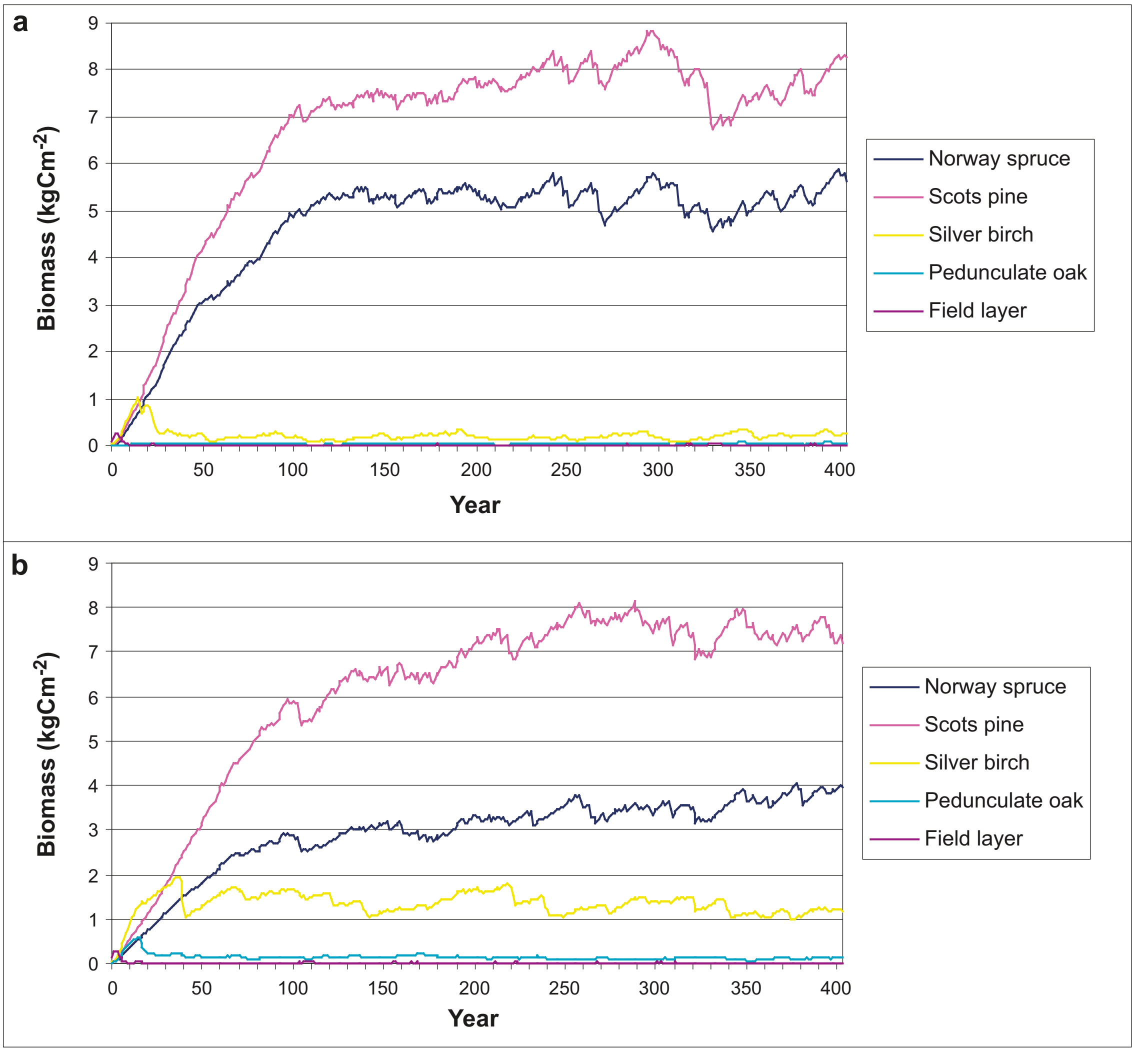


Figure 7-6. *Total biomass during the succession after clear-cut (year 0) in a forest in (a) Forsmark and (b) Laxemar-Simpevarp for four different tree species and the field layer during a 400-year period. The model was driven by climate data describing a 100-year period that was repeated. Values are given in kgC* m^{-2} y^{-1}.

7.3.2 Temporal variation in carbon balances

Temporal variation in a 400-year forest cycle

After a clear-cut, forests were dominated by pine and spruce in both Forsmark and Laxemar-Simpevarp. The pattern was more accentuated in Forsmark. The deciduous trees occurred early in the succession, but were later suppressed by the coniferous species. There was a larger fraction of deciduous trees in Laxemar-Simpevarp than in Forsmark. The field layer never became important with regard to biomass except for the first year, Figure 7-6. The total biomass continuously increased during the first 100–200 years and then levelled off.

NPP increased sharply during the first 50 years and reached its peak after about 100 years, after which it decreased slowly (for coniferous species), Figure 7-7. This slow decrease occurred at the same age as biomass levelled out (Figure 7-6).

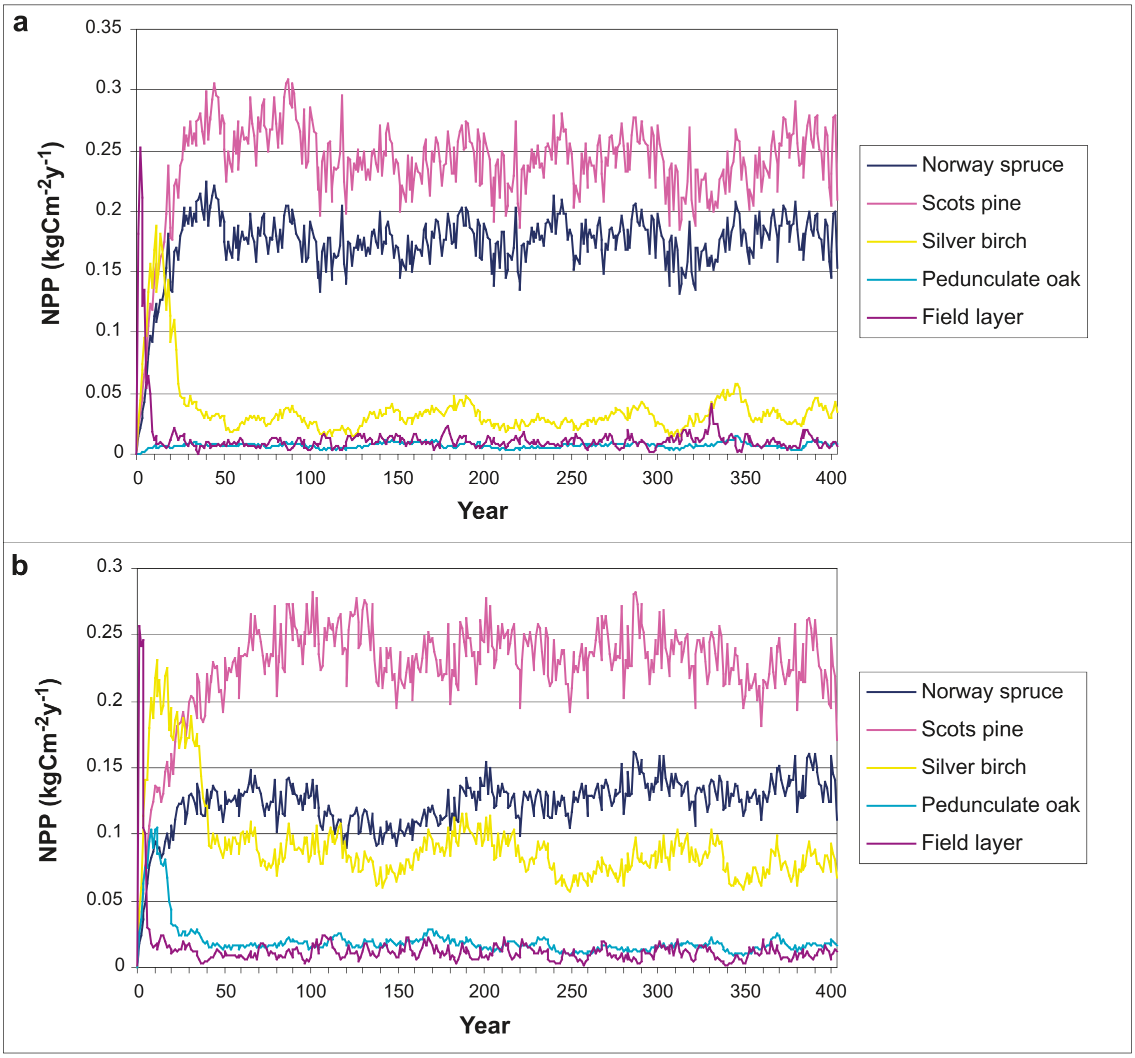


Figure 7-7. *Net primary production during the succession after clear-cut (year 0) in a forest in (a) Forsmark and (b) Laxemar-Simpevarp for four different tree species and the field layer during a 400-year period. The model was driven by climate data describing a 100-year period that was repeated. Values are given in kgC m^{-2} y^{-1}.*

Net ecosystem exchange of carbon was negative in the beginning of the forest cycle. More carbon was respired to the atmosphere than was photosynthesized by the growing vegetation, due to litter leftovers from clear-cutting of the forests. This relationship changed after 9 years in Forsmark and 6 years in Laxemar-Simpevarp. At this time the emerging vegetation after clear-cut had increased its leaf biomass to the extent that photosynthesis and thereby carbon uptake balanced the heterotrophic respiration. Moreover, much of the litter from the clear-cut was already respired, Figure 7-8. After about 100 years, NEE levelled off at an average of 55 gC m^{-2} y^{-1} in both investigation areas. This occurred when biomass accumulation levelled off.

Immediately after the clear-cut the litter pool was large, but it decreased rapidly during the first 17 years in both Forsmark and Laxemar-Simpevarp. It subsequently increased slowly in Forsmark, reaching an equilibrium after 175 years, whereas in Laxemar-Simpevarp the litter pool reached equilibrium after the heavy decrease. For the first 9 years the SOC pools increased as carbon from the litter pool was decomposed. During the following 100 years there was a slight decline in the SOC pools in both Forsmark and Laxemar-Simpevarp, which reached equilibrium with few changes for both investigation areas, Figure 7-9.

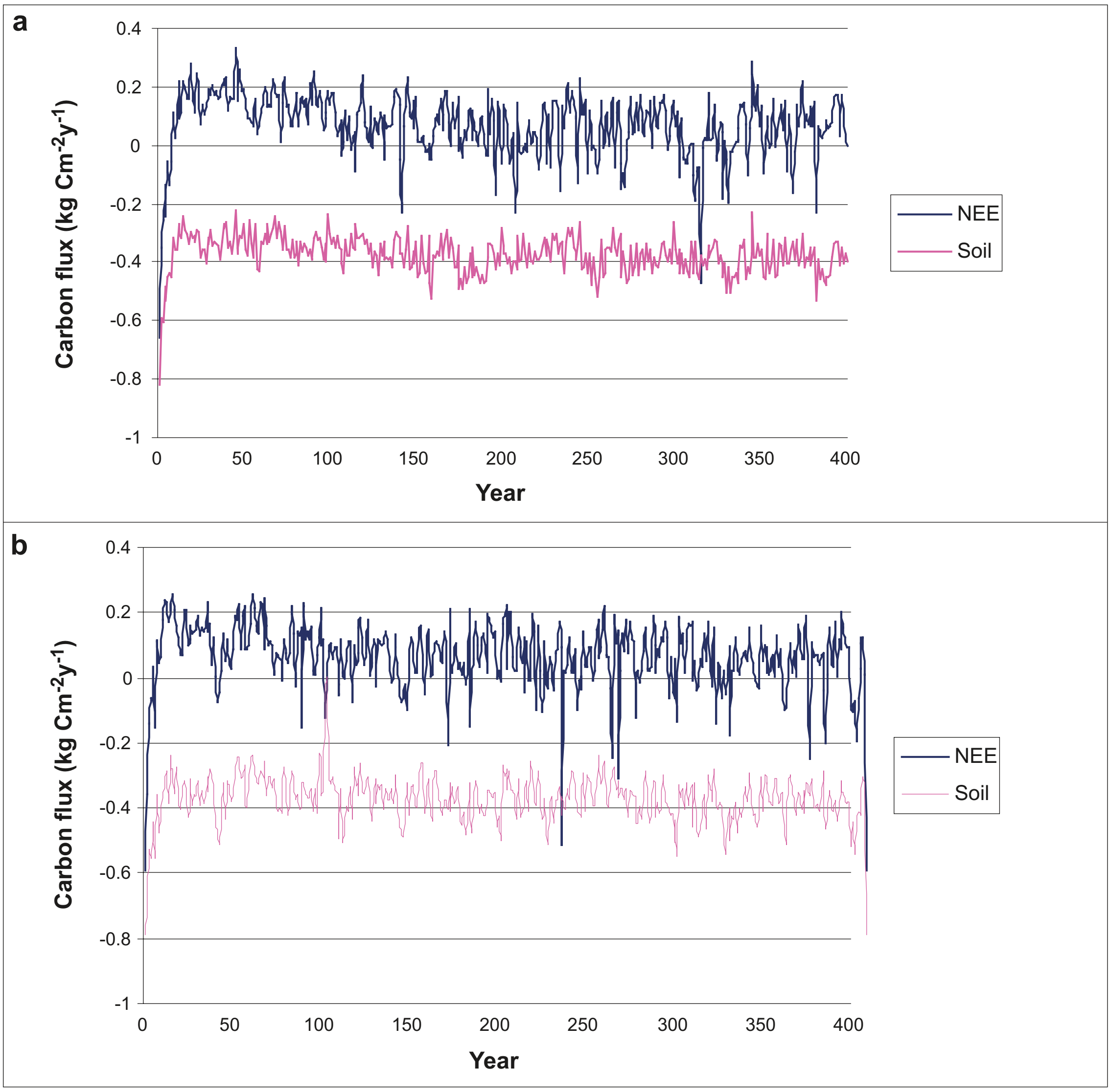


Figure 7-8. *Heterotrophic soil respiration in a forest during a period of 400 years starting after a clear-cut for (a) Forsmark and (b) Laxemar-Simpevarp. The model was driven by climate data describing a 100-year period that was repeated. Values are given in kgC m^{-2} y^{-1}.*

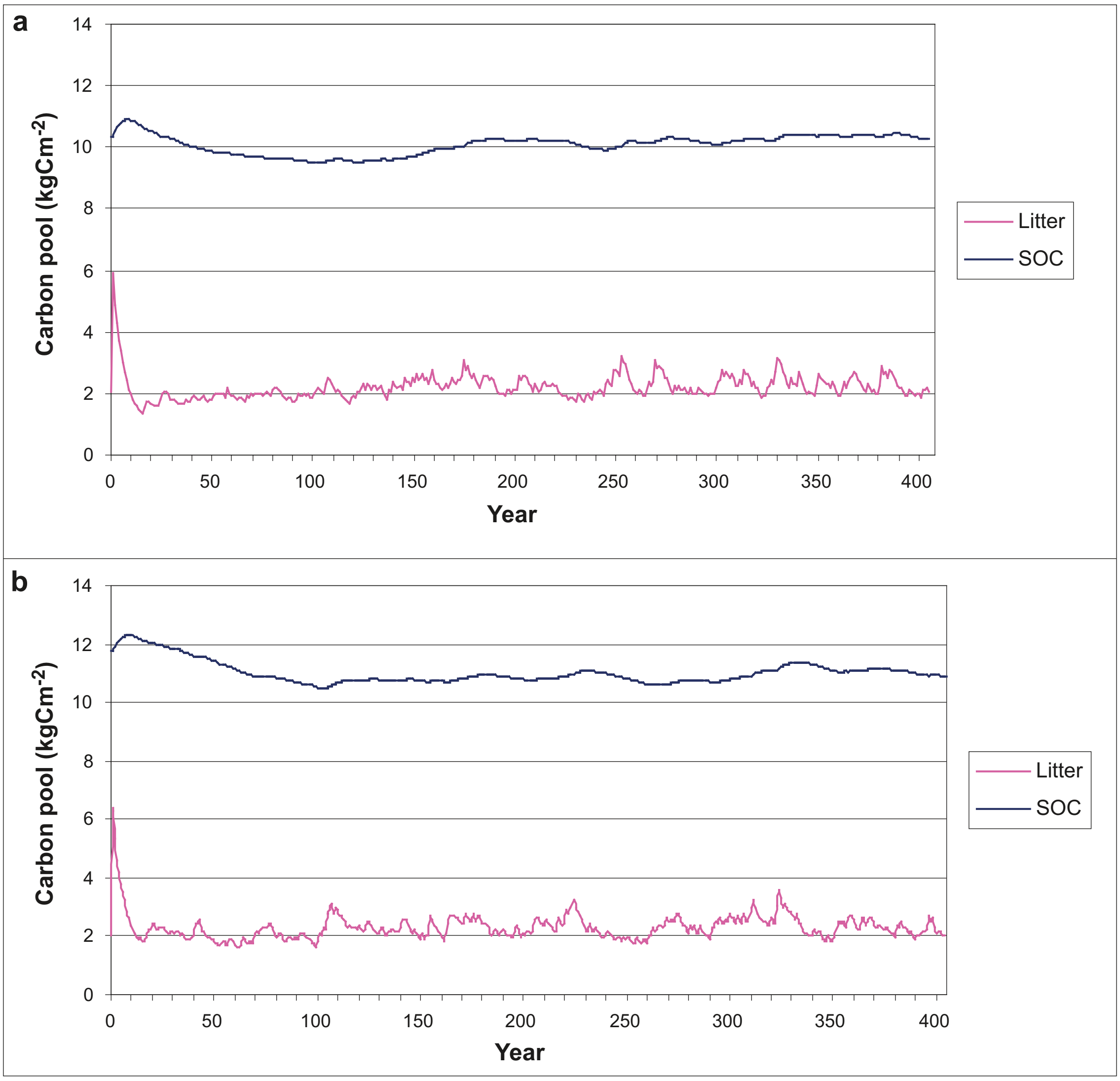


Figure 7-9. *Litter and soil organic carbon (SOC) pools in a forest during a period of 400 years starting after a clear-cut for (a) Forsmark and (b) Laxemar-Simpevarp. The model was driven by climate data describing a 100-year period that was repeated. Values are given in kgC* m^{-2} y^{-1}.

Temporal variation in a 100-year forest cycle

Average values of carbon balances during a 100-year forest cycle (after which period a commercially managed forest is felled) are illustrated in Figure 7-10. There was a positive uptake of carbon in both investigation areas, i.e. more carbon was added to the vegetation than was lost due to respiration. This can be explained by the fact that biomass was mainly accumulated during the first 100 years.

Descriptive statistics are shown in Table 7-7 and mean, standard deviation and median values are based upon the 100-year perspective. Maximum values were taken from the 400-year perspectives since maximum values show the potential peak of the ecosystem property.

Temporal variation in carbon balances for arable land

Crop NPP (397 gC m^{-2} y^{-1}) and crop yield (182 gC m^{-2} y^{-1}) were rather similar in Forsmark and Laxemar-Simpevarp, Table 7-8. In the agricultural areas, there was a 6 gC m^{-2} y^{-1} net accumulation of SOC in Laxemar-Simpevarp, while 3 gC m^{-2} y^{-1} was accumulated in Forsmark. This accumulation was mainly caused by the large input of biomass that was left in the field after bringing in the yield.

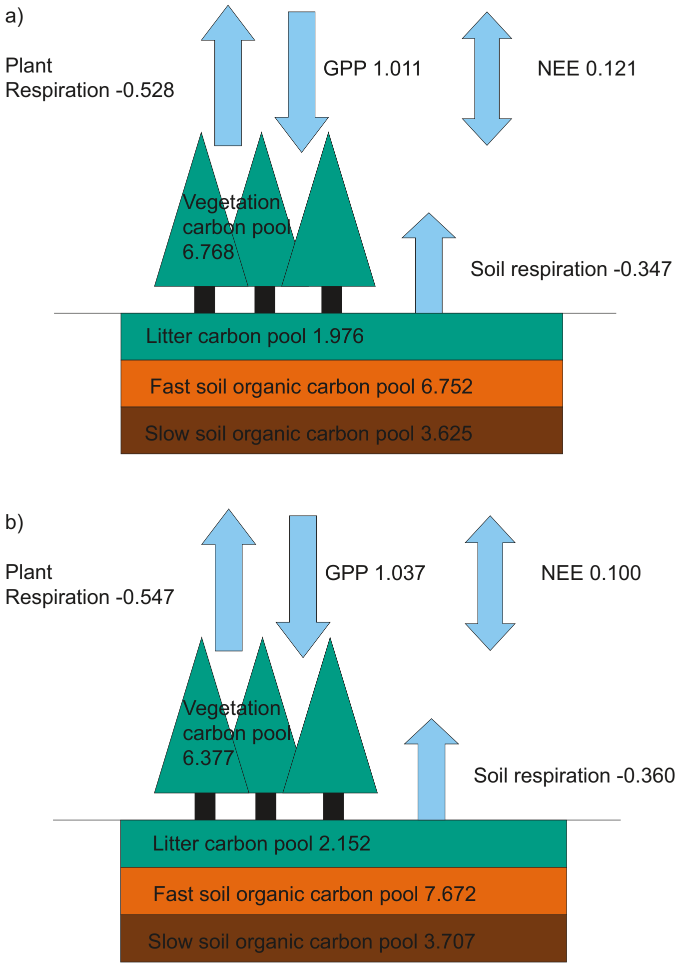


Figure 7-10. *Summary of the dominant carbon fluxes and carbon pools for a 100-year forest cycle until final felling in a) Forsmark and b) Laxemar-Simpevarp. Values are given in kgC* m^{-2} *for the carbon pools and kgC* m^{-2} y^{-1} *for the carbon fluxes.*

Table 7-7. Mean, standard deviation and median of the temporal variation in some ecosystem properties during the first 100 years and maximum values during the 400-year forest cycle for Forsmark and Laxemar-Simpevarp. Values are given in gC m^{-2} for the carbon pools and gC m^{-2} y^{-1} for the carbon fluxes.

Property	Forsmark mean±sd	median	max	Laxemar-Simpevarp mean±sd	median	max
LAI_{tree}	3.31±0.78	3.54	3.96	3.28±0.62	3.41	3.94
NPP_{tree}	459±103	482	736	464±84	479	562
$\text{NPP}_{\text{field}}$	19±40	9	252	20±43	11	257
$\text{Biomass}_{\text{tree}}$	6,403±3,433	7,099	14,524	6,052±2,868	6,041	12,986
$\text{Biomass}_{\text{treegreen}}$	170±47	189	210	148±32	158	172
$\text{Biomass}_{\text{treeroot}}$	171±47	189	212	151±33	160	193
$\text{Biomass}_{\text{treetotal}}$	6,744±3,536	7,509	14,896	6,351±2,945	6,353	13,325
$\text{Biomass}_{\text{field}}$	23±45	11	269	26±48	14	279
Litterfall	335±120	335	1,128	338±128	322	1,022
$\text{Respiration}_{\text{soil}}$	–347±80	–335	–819	–360±87	–350	–787
Litter	1,976±493	1,894	3,214	2,152±566	2,009	5,314
SOC	10,016±424	9,847	10,892	11,379±555	11,380	12,290
NEE	121±131	148	658	100±122	121	592

Table 7-8. Descriptive statistics of NPP, harvest of crop and accumulation of soil organic carbon (SOC) during 100 years in gC m^{-2} y^{-1}.

Property	Forsmark mean±sd	median	Min – max	Laxemar-Simpevarp mean±sd	median	Min. – max.
NPP	395±51	398	255–584	399±46	400	249–583
Yield*	185±22	186	125–241	178±22	178	123–271
$SOC_{accumulation}$	3±4	2	–4–16	6±6	6	–8–21

* 66% of aboveground biomass (Olsson, HIR Malmöhus pers. comm.).

7.4 Discussion

7.4.1 Validations of the dynamic vegetation model

Unlike other more detailed models, LPJ-GUESS simulates carbon and vegetation dynamics directly on the basis of local climate, which makes the model very applicable. Several studies has compared the output of LPJ-GUESS and the closely related DGVM LPJ with the output of more detailed models, and even though they are driven by few parameters, robust results have been obtained for carbon balances and vegetation distribution /Bachelet et al. 2003, Cramer et al. 2001, Jung et al. 2007, Badeck et al. 2001/. The models have also been evaluated against field estimates of carbon, vegetation dynamics and water exchange across Europe /Sitch et al. 2003, Morales et al. 2005/. Along a European continental temperature gradient, LPJ predicts the general trends in LAI and GPP well in comparison with site data /Jung et al. 2007/. LPJ-simulated FAPAR was also comparable with remote-sensed estimates /McCloy and Lucht 2001/. LPJmL, a model developed for managed planetary land surface, was used to simulate the spatial distribution of sowing dates for temperate cereals, and the outputs were comparable with reported crop calendars /Bondeau et al. 2007/. Simulated yields for temperate cereals and maize were in good agreement with estimates from the FAO (Food and Agriculture Organization of the United Nations /Bondeau et al. 2007/). Fluxes of carbon over agricultural areas were also accurately described by the simulations /Bondeau et al. 2007/. In a study aiming at adapting LPJ-GUESS to African biomes, /Hély et al. 2006/ showed that model-estimated LAIs were in good agreement with remote-sensed estimates of LAI. For the same African biomes, the modelled vegetation composition agreed well with the vegetation cover obtained from a vegetation map and pollen data /Hély et al. 2006/.

Vegetation patterns, phenology and vegetation structure were accurately described by LPJ on a global basis /Sitch et al. 2003/. /Badeck et al. 2001/ showed that LPJ-GUESS correctly simulated the dominant plant functional types (PFTs) at five European pristine forest sites, and /Smith et al. 2001/ also correctly predicted the PFT composition of observed natural vegetation at various sites across Europe. LPJ-GUESS simulated vegetation dynamics, tree species composition and biomass accurately at three sites in the region of the great lakes, USA /Hickler et al. 2004/. LPJ also captured the broad patterns of vegetation distribution across the USA well /Bachelet et al. 2003/. The models have been used in several other applications such as palaeo-ecological changes and their link to climate dynamics /Ni et al. 2006, Lunt et al. 2007/, hydrological features e.g. evapotranspiration and runoff /Morales et al. 2005, Gerten et al. 2004/ and threshold responses of ecosystems to changing climates /Cowling and Shin 2006/.

7.4.2 Model limitations and parameter uncertainties

The development of process-based ecosystem models involves many assumptions and uncertainties. Inaccuracies mainly arise from the input data driving the simulation, the mathematical descriptions of the mechanisms behind the ecosystem processes and the parameters set in these functions to scale the mathematical estimates /Zaehle et al. 2005/. General considerations of the LPJ-GUESS model involve the simplifications of the disturbance regime, the lack of anthropogenic influences, nutrition limitations and parameter uncertainties.

The disturbance regime in LPJ-GUESS was simplified to a mean disturbance interval of 100 years. This is the average return time for natural disturbances such as fire /Zackrisson 1977/. Climate changes influence the disturbance regime so that fires, diseases, pests and extreme weather events become increasingly common as the temperature increases. LPJ-GUESS is commonly used for predictions of vegetation dynamics under changing climate conditions, so changes in the disturbance regime should therefore be incorporated into the model. Nevertheless, under modern conditions 100 years is the average return time for natural disturbances /Zackrisson 1977/ and it has also been used in several earlier modelling studies /Koca et al. 2006/.

Another limitation of the model is that land use practices and anthropogenic effects on vegetation dynamics were not included in the model. Both carbon and vegetation dynamics are highly influenced by both human management and unintentional human-induced effects. Forest management practices – for example soil scarification (chopping or ditching), thinning, competition control and fertilization – alter carbon and vegetation dynamics and should therefore be taken into account as well /Tyree et al. 2006/. No crop management was incorporated into the model, and the only factors that distinguished crops from C_3 grass were the root to leaf ratio and the fact that no roots survived the winter. An improvement would be to include management practices such as conventional tillage or no-till farming, crop rotation, leaving crop residue mulch and fertilization /West and Post 2002, Lal 2007/. Other factors that may be important to include are climate-dependent sowing and harvesting periods and more species-specific parameterization of the crops used in the investigation areas. Including anthropogenic influences is an important next step in future development of the model.

The model does not take into account the possible small-scale heterogeneity of environmental variables and the nutritional status of the soils. Small-scale heterogeneity can affect spatial variation in carbon balances as well as vegetation dynamics. Nitrogen can both be a limiting factor and a fertilizer of plant production. It could be important to include nitrogen constraints on NPP to limit NPP and to make sure that it is not overestimated. The net effect of nutrients on carbon balances is hard to predict, but several studies have shown that NPP is accurately predicted even if the model does not include a nutrient module e.g. /Koca et al. 2006, Bondeau et al. 2007, Cramer et al. 2001, Hickler et al. 2006/. A negative effect of including nutrient limitations is that parts of the generality and the simplicity of the model are lost when additional complex modules are included.

/Zaehle et al. 2005/ performed an uncertainty analysis of the parameters in LPJ to elucidate what the most important parameters are for controlling carbon balances. They came to the conclusion that the most important factor influencing NPP, heterotrophic respiration and vegetation carbon pools is the constant for intrinsic quantum efficiency (0.08 in this study). This is the constant that gives the intrinsic slope of the correlation between GPP and PAR, determining the amount of carbon taken up by photosynthesis per amount of solar radiation. The second most important factor for NPP and heterotrophic respiration is the constant determining the amount of PAR that is lost due to absorption of non-photosynthetic structures (0.4 in this study) such as stems and branches. These factors alter the uptake of solar radiation, leading to changed NPP and thereby changes in LAI and other carbon fluxes such as heterotrophic respiration. The second most important factor for the vegetation carbon pool was the turnover rate of sapwood (Table 7-3), while for the litter carbon pool it was the turnover rate of litter (Table 7-3). Other important factors are the shape parameter (0.7 in this study), describing the convex relationship between the GPP-PAR relationship and the light use efficiency constant /Zaehle et al. 2005/. There are also other species-specific parameters that alter the shape and allometry of the tree, naturally affecting LAI as well as the vegetation carbon pool and NPP. Wood density is another parameter, and with higher wood density less carbon can be allocated to, for example, leaves. Leaf longevity is an important parameter affecting the amount of leaves on the branches. Even though uncertain parameters can result in propagation errors, /Zaehle et al. 2005/ showed that the overall response of simulated carbon fluxes in LPJ to climate variation was relatively robust.

The model is adapted to global circumstances and not specifically Nordic environments. It has been shown in a comparison of standard deviation of modelled results and measurements that uncertainties are higher at northern latitudes than in the more southern and tropical regions /Zaehle et al. 2005/. In particular, the parameters in the photosynthesis module are more sensitive at northern latitudes. /Zaehle et al. 2005/ showed that increasing the constant determining the amount of PAR that is lost due to absorption of non-photosynthetic structures and the intrinsic quantum efficiency increases the agreement between model and field estimates at northern latitudes. The parameters that contribute the most to uncertainties in LPJ, are, however, quite well known. The model has little sensitivity to the parameters that are more uncertain (for example descriptions of allometry, stand structure and fire dynamics) /Zaehle et al. 2005/.

7.4.3 Evaluation of the dynamic vegetation model

Leaf area index

Generally, the modelled LAI was acceptable and realistic compared with both field estimates and other studies, which have a range between 1.2 and 8.4 (average 3.6 of 54 studies)) /Chen et al. 1997, Fassnach and Gower 1997/. The direct correlation with field-estimated LAI was not significant, and the reason for this was one of the deciduous stands, a dense oak stand with very large LAI. If the dense oak stand is omitted, the correlation will be significant (0.74, p-value 0.006). The model estimates more of an average value for the area, so these large values were not well simulated. This is the reason why the comparison with NDVI-estimated LAI (an average estimate for the investigation areas) was better correlated. For deciduous stands, the modelled LAI and the NDVI-estimated LAI were the same (2.50).

Soil respiration

The model underestimated soil respiration compared with measured values. One explanation could be that field estimates of soil respiration included all CO_2 respired from the ground, whereas model estimates did not include leaf respiration from the field layer and respiration from coarser roots was not included in root respiration but in sapwood respiration. However, the field layer should only have a minor effect, since only sparse field layers were seen in the forest stands where the measurements were performed /Tagesson and Lindroth 2007/. A large fraction of root respiration originates from fine roots, which was included in modelled soil carbon respiration /Pregitzer et al. 1998, Widén and Majdi 2001, Saiz et al. 2007/. Moreover, different studies have different boundaries between fine and coarse roots, e.g. /Widén and Majdi 2001/ and /Pregitzer et al. 1998/ adopted 5 mm whereas /Saiz et al. 2007/ adopted 3 mm as a boundary. In the model the boundary was set at 2 mm /Matamala and Schlesinger 2000/, and a smaller fraction of total root respiration was included in fine root respiration, resulting in lower modelled soil respiration in comparison with field estimates.

Even though the model gave lower estimates than the field estimates, they were in the same range (between 281 and 459 gC m^{-2} y^{-1}) as literature values of field-estimated soil respiration. In a review by /Raisch and Schlesinger 1992/, the soil in boreal forests respires on average 324 gC m^{-2} y^{-1}. Similarly, soil respiration in the pasture, with an estimate of 308 and 327 gC m^{-2} y^{-1} for Laxemar-Simpevarp and Forsmark, respectively, was in the lower interval compared with field estimates of between 273 and 756 gC m^{-2} y^{-1} /Maljanen et al. 2001, Suyker and Verma 2001, Flanagan et al. 2002, Suyker et al. 2003/. /Tagesson and Lindroth 2007/ attributed their high field-estimated values either to errors in the estimation technique or the fact that several of the forest stands were managed. For example, one of the field estimates was from a spruce forest stand in Laxemar-Simpevarp on newly ditched peat. Site management alters primary production and this influences soil respiration. These factors were not included in the model.

Net primary production

Model-estimated Net Primary Production (NPP) was on average 514 gC m^{-2} y^{-1}, while LAI-estimated NPP was high at 540 gC m^{-2} y^{-1}compared with literature values. According to /Gower et al. 2001/, who used field measurements of stem increment, litterfall and root biomass, NPP values in Sweden and Finland for the boreal forests were between 210 and 460 gC m^{-2} y^{-1}. However, this was based on a few study sites. /Zheng et al. 2004/ combined remote-sensed data from the Advanced Very High Resolution Radiometer (AVHRR) and field estimates for spatial distribution of NPP over Sweden and Finland and showed that Forsmark and Laxemar-Simpevarp are in regions with high NPPs, which explains the higher values. Field estimates from two forests stands in Forsmark and two in Laxemar-Simpevarp were 454 gC m^{-2} y^{-1}, 537 gC m^{-2} y^{-1}, 591 gC m^{-2} y^{-1} and 736 gC m^{-2} y^{-1}, see Chapter 6. Other studies have also obtained large NPPs for these regions. For Norunda in the region of Forsmark, /Lagergren et al. 2005/ obtained NPP values between 710–940 gC m^{-2} y^{-1} with an average of 810 gC m^{-2} y^{-1}, and /Olofsson et al. 2006/ obtained values between 660 and 890 gC m^{-2} y^{-1}.

In the comparison with field estimates of stem increment, conversion factors for modelled NPP included several uncertainties. Smaller factors have been used in the past /Eriksson 1991, Nabuurs et al. 1997/, and if Eriksson's conversion factors were used instead, average model- and LAI-based NPP converted to stem increment would be 6.421 and 6.749 m^3 ha^{-1} y^{-1}, respectively, i.e. significantly closer to the field estimates of 5.911 m^3 ha^{-1} y^{-1}.

Forest net ecosystem exchange

A large range of NEE values are found for boreal forests, from a small loss of carbon at the Norunda site (52 gC m^{-2} y^{-1}) /Lagergren et al. 2008/ to a large gain of about 1,300 gC m^{-2} y^{-1} in an aspen forest in central Saskatchewan /Black et al. 1996/. Many different estimates have been recorded falling between these extremes e.g. /Goulden et al. 1997, Kolari et al. 2004, Lagergren et al. 2008/. Model-estimated NEEs (72±167 and 177±106 gC m^{-2} y^{-1} in Laxemar-Simpevarp and Forsmark, respectively) were in the intermediate range of most studies. One major outlier can be seen in Laxemar-Simpevarp: the old spruce forest with a loss of –194 gC m^{-2} y^{-1}, which was caused by the stochastic fire disturbance regime since as much as –415 gC m^{-2} y^{-1} was lost due to fire.

Crop and grass net ecosystem exchange

In the grasslands and agricultural areas in both Forsmark and Laxemar-Simpevarp, modelled NEE indicated that there was a net uptake of carbon (between 63 and 150 gC m^{-2} y^{-1}). In Laxemar-Simpevarp, field estimates of NEE suggested a net emission of between 0 and 380 gC m^{-2} y^{-1} for agricultural fields /Tagesson 2007/, while for grasslands the net emission of carbon was between 375 and 651 gC m^{-2} y^{-1} /Tagesson and Lindroth 2007/. /Tagesson and Lindroth 2007/ attributed the net emission to meadow drainage, a disturbance not included in the model. Other studies have obtained NEE values more similar to the model, and there is a wide range of NEE estimates from net emission to accumulation (–950 to 274 gC m^{-2} y^{-1}) /Suyker et al. 2003, Flanagan et al. 2002, Novick et al. 2004, Maljanen et al. 2001, Byrne et al. 2005, Soegaard et al. 2005, Hollinger et al. 2005/.

Crop and grass gross primary production

The only field estimates that could be compared to modelled GPPs were from a pasture and an agricultural field in Laxemar-Simpevarp. Model-estimated GPPs (773 gC m^{-2} y^{-1}) for pastures were higher than field estimates (52 gC m^{-2} y^{-1}), even the difference was not significant /Tagesson and Lindroth 2007/, whereas the agricultural areas were accurately simulated (field: 710±270 gC m^{-2} y^{-1}; model: 750 gC m^{-2} y^{-1}) /Tagesson 2007/. Modelled GPPs for the field layer in the pasture and the agricultural field were similar compared with a number of grassland studies in which the estimates varied between 270 and 1,210 gC m^{-2} y^{-1} /Flanagan et al. 2002, Suyker and Verma, 2001, Suyker et al. 2003, Novick et al. 2004/.

Biomass

Field data were only available from four forest stands in a comparison with the model (Laxemar-Simpevarp: 1 old spruce, 1 deciduous; Forsmark: 2 old spruce). Nevertheless, data for the four forest types were checked for normal distribution by a Kolmogorov-Smirnov test and average values and standard deviations were calculated (Table 7-9).

Modelled tree wood biomass seemed to be slightly higher than the field estimate. Modelled biomass was high in a comparison with other studies as well. In a review by /Jarvis et al. 2001/, estimated total biomass for boreal forests ranged from 500 gC m^{-2} to 6,500 gC m^{-2}, with an average value for boreal forests in Western Europe of 5,100 gC m^{-2} y^{-1}. Biomass varied depending on ecosystem features such as species, age, climate, disturbance interval, latitude, soil character and nutrient availability, explaining the wide ranges of values /Jarvis et al. 2001, Giese et al. 2003/.

Modelled leaf carbon estimates were lower than field measurements (Table 7-9). The leaf carbon fraction of the total carbon pool was 0.02, which was half the fraction used by /Nabuurs et al. 2003/. The main parameter affecting leaf carbon mass is the leaf to root fraction. In the model, the maximum value of this parameter was set at one, but it was reduced due to water stress and was estimated to be 0.5–0.7. This is similar to values estimated in other field studies /Oleksyn et al. 1999/. According to field estimates from the investigation areas, this fraction should be as high as 2.91. Increasing the leaf to root fraction would also increase NPP in the upper part of its range.

Modelled field layer carbon estimates were less than the field estimates, probably due to the large estimated tree carbon pool. Uptake by trees represents a large fraction of incoming PAR and may therefore reduce the available light for the field layer.

Litterfall

Field measurements of annual input of above-ground litter from trees at three sites in Laxemar-Simpevarp and two sites in Forsmark were performed using circular litter traps with a nominal sampling area of 0.32 m^2 for 2004–2006 /Mjöfors et al. 2007/. Model-estimated total litter production was compared with field estimates of above-ground litterfall. Field estimates were available for 2004–2005 and for 2005–2006 /Mjöfors et al. 2007/. Average values of these two years were used for the model-estimated litter production and compared with the field estimates using a Pearson correlation. For all sites in both Forsmark and Laxemar-Simpevarp, average above-ground litterfall estimated in the field was 115±56 gC m^{-2} y^{-1}, whereas modelled total litter production was 504±23 gC m^{-2} y^{-1}. The Pearson correlation test indicated that there was no correlation between field-estimated above-ground litterfall and model-estimated total litter production (n= 10, Pearson correlation 0.08, *p*-value 0.83). /Saarsalmi et al. 2007/ estimated about the same amount of litterfall (119 gC m^{-2} y^{-1}) as the field estimates for differently aged boreal forests over Finland 1961–2002. One reason for high model estimates of the litter production was that the modelled litterfall was all carbon moved from the vegetation pool to the litter pool, including both carbon moved from the living vegetation and mortality, while the field estimates comprised only above-ground litterfall from needles/leaves, twigs (Ø ≤ 5 mm), cones, seeds and flake bark from trees, leaving larger branches and roots.

Table 7-9. Mean biomass (±SD) of different components in four forest types as estimated by field studies and modelling. Values given in gC m^{-2}.

Property	Field	Model
Tree leaves	481±197	162±66
Tree wood	6,745±1,813	7,926±1,323
Tree fine roots1	166±52	162±66
Grass leaves	19±18	11±3
Grass roots	68±60	23±6

[1] Fine roots < 2 mm.

Soil organic matter

Field estimates for the investigation areas indicate an average of 6,340 gC m^{-2} for the SOC pool and 490 gC m^{-2} for the litter pool. This was much lower than the model estimates for the same ecosystem types, with 10,770 gC m^{-2} for the SOC pools and 2,390 gC m^{-2} for the litter pool. The field estimates were also lower than the mean for Sweden of 8,200 gC m^{-2} /Olsson et al. 2008/, which in turn was much lower than average estimates of SOC for boreal forests of, in general, around 15,000 gC m^{-2} /Schlesinger 1977, Pregitzer and Euskirchen 2004/. The latter figure was similar to the sum of the modelled litter, fast and slow SOC pools. An explanation of the discrepancy between field estimates and model estimates is that both Laxemar-Simpevarp and Forsmark are situated close to the coast, where the soils are young, resulting in a lower amount of SOC in comparison with average values for boreal forests /Lundin 2004 and 2005a/. The high soil respiration estimated in the field could also be a result of easily decomposed litter, which would lead to a small amount of litter in the field. Field estimates were very low in comparison with average values for boreal biomes, and the forests in Laxemar-Simpevarp and Forsmark do not have more litter than the average soils of grasslands /Schlesinger 1977/.

7.4.4 Spatial variation in net primary production

Previous studies have shown significant differences in NPP on different spatial scales. Climate is a major factor influencing NPP /Runyon et al. 1994/ and there are differences in climate within the investigated areas. It is wetter and warmer near the coast than further inland, even though the distance is only a couple of kilometres /Johansson et al. 2005, Larsson-McCann et al. 2002ab/. Other properties that differ within the investigation area that affect NPP are species composition, age of forest, forest management, humus quality, sap conductivity, elevation, topographic gradients, soil properties, site water balance and nutrient availability /Burrows et al. 2003, Ahl et al. 2004, Albaugh et al. 2004, Fassnach and Gower 1997, Le Dantec et al. 2000, Samuelson et al. 2004/.

The estimates indicated much greater variation in NPP in Forsmark than in Laxemar-Simpevarp, (Table 7-6). The relationship between LAI and NPP is of an exponential character with a negative coefficient, i.e. at a certain level NPP reaches saturation and does not increase with LAI. LAI values for several ecosystem types are higher in Laxemar-Simpevarp than in Forsmark (Table 7-6), and NPP estimates are, therefore, closer to this saturation level, which gives lower variation. For the ecosystems with the same LAI or even lower LAI in Laxemar-Simpevarp, variation in NPP was still lower because NPPs for these ecosystem types are lower in Laxemar-Simpevarp (Table 7-6) and the saturation level was thereby reached at an earlier stage.

Today, data from land inventories, satellite imagery, research observations and dynamic vegetation modelling is often integrated to examine spatial and temporal patterns of ecosystem properties and processes e.g. /Liu et al. 1999, Knorr and Heimann 2001, Chen et al. 2003, Nemani et al. 2003, Knorr et al. 2004, Zheng et al.2004/. In an error analysis, /Knorr and Heimann 2001/ found that the sensitivity of the input parameters of the model was significantly reduced when satellite data were incorporated. In order to produce consistent results, dynamic vegetation models need correct input data. Remote sensing produces reliable input data on such factors as land use, soil quality and forest structure. /Smith et al. 2008/ performed an analysis of the accuracy of dynamic vegetation modelling alone and two different methods combining remote sensing with dynamic vegetation modelling. Their results suggest that the method using a model in combination with satellite data on vegetation structure gave the most accurate results.

In this study, we have quantified spatial distribution of NPP, an important parameter in the quantification of carbon budgets. However, other parameters are equally important for a large-scale understanding of the spatial distribution of carbon balance. Thus, it is important to find ways of estimating other parts of carbon balance in the investigation areas. All ecosystem carbon pools and fluxes are estimated in dynamic vegetation models, and using this information to estimate key ecosystem responses to satellite-based information should be a straightforward method for completing the picture of the carbon balances of a region.

7.4.5 Temporal variation in carbon balances for forested areas

Generally, in a 400-year perspective, the forest stands reach an equilibrium with regard to carbon fluxes after between 150 and 200 years, Figures 7-6 to 7-9. A natural forest stand reaches a dynamic equilibrium after some time with a certain amount of young and old trees, due to disturbances and/or mortality. A general problem with the model is that it is designed for natural, not managed ecosystems. It is impossible to simulate stands with 400-year-old trees, since disturbances are included and the model is not local but regional. Average stand values are therefore simulated.

Vegetation dynamics

Generally, LPJ-GUESS simulated species composition and vegetation dynamics well (Figure 7-6). Boreal forests follow a common successional pattern after a major disturbance /Bergeron 2000/. In a young forest, sapling trees such as birch are common and hardwood plants dominate. Coniferous species begin growing among the hardwoods, but their growth is slow. In the second phase, as the stand matures and coniferous trees start to dominate, the hardwood species die off. Finally, in the climax state the canopy is more open and coniferous trees are the most common. A few deciduous trees grow in the openings. The model follows these successional stages well. During the first few years silver birch dominated, then after about ten years coniferous and deciduous species were equally common, and finally coniferous forests dominated. This tree-age dynamic was similar to the vegetation dynamics reported by /Bergeron 2000/.

In a comparison between modelled biomass (an as average for forests in equilibrium, i.e. the 300–400-year old forest) and an area occupied by the different species in the /Boresjö Bronge and Wester 2003/ vegetation map, species composition was simulated acceptably (Table 7-10). Pine was most common both in the field and in the simulations. In Forsmark, deciduous trees were more common in the field than in the model, whereas the model accurately approximated the situation in Laxemar-Simpevarp. Spruce trees were more common in the model than in the simulations for both investigation areas. The model simulated natural ecosystems well, whereas both investigation areas are highly influenced by forest management. Thus, it was difficult to make a comparison between the modelled tree vegetation at the end of the time series and the vegetation map describing the forest composition today.

Biomass

Generally, biomass increases until a certain age, where the biomass accumulation levels off. The explanation is that NPP and maintenance respiration reach equilibrium and more biomass cannot be accumulated. /Pregitzer and Euskirschen 2004/ estimated this age to be between 120 and 200 years, which is roughly the same age as when carbon mass was saturated in the model (Figure 7-6).

Table 7-10. Species composition in Forsmark and Laxemar-Simpevarp as simulated by the model and as fraction area of the vegetation map by /Boresjö Bronge and Wester 2003/.

Vegetation type	Forsmark		Laxemar-Simpevarp	
	Field	Model	Field	Model
Norway spruce	0.25	0.40	0.09	0.29
Scots pine	0.49	0.58	0.82	0.60
Deciduous	0.27	0.02	0.09	0.11

Net primary production

Young stands have a high NPP. This is caused by increasing LAI with age so that more carbon can be accumulated. NPP reaches its peak at the maturity of the stands and then starts to decline with age (Figure 7-7). After between 150 and 200 years, NPP reaches equilibrium and it does not change at all. /Gower et al. 1996/ explained a decrease in above-ground NPP by decreasing soil nutrient availability and increasing hydraulic resistance in the stomata, which decreases water conductivity. /Binkley et al. 2002/ explain the decline in forest growth by competition-related changes in stand structure, where fewer large dominant trees sustain their resource efficiency at a cost of the resource efficiency of smaller non-dominant trees. /Smith and Long 2001/ have a similar explanation: the decline in forest growth is a result of canopy closure and interference between tree crowns. These factors affect production of foliage of the stands, resulting in a decrease in NPP with age /Smith and Long 2001, Binkley et al. 2002, Kashian et al. 2005/.

Net ecosystem exchange

/Kolari et al. 2004/ estimated NEE for four differently aged spruce stands in Finland. NEE changes with age, and they reported that 4 years after clear-cutting the forest stand acted as a source of carbon and 386 gC m^{-2} y^{-1} was lost to the atmosphere. In both Laxemar-Simpevarp and Forsmark the model estimate was a loss of about 140 gC m^{-2} y^{-1}, but only the year before the loss was estimated to be 360 and 256 gC m^{-2}, respectively. In a 12-year old stand, /Kolari et al. 2004/ estimated NEE to be about 0 gC m^{-2} y^{-1}, whereas this was reached after 7 years in Laxemar-Simpevarp and 9 years in Forsmark. After that, forests generally start to be sinks of carbon and accumulate carbon in the vegetation and in the SOC pools. NEE of 40-year old stands in Finland was between 172 and 192 gC m^{-2} y^{-1}, which is similar to the model estimates at Forsmark and Laxemar-Simpevarp. In the Finnish study, the carbon sink increased with age, and at the age of 75 years stands had an NEE of 323 gC m^{-2} y^{-1}. In Laxemar-Simpevarp and Forsmark, however, it decreased slightly with forest age, and at the age of 70–79 average NEE was 121 gC m^{-2} y^{-1}. After that, the forest achieves equilibrium and for the 100 to 400-year old stands, NEE was on average 55 gC m^{-2} y^{-1}, i.e. a small sink of carbon (Figure 7-8).

Soil respiration

A pattern with high soil respiration in forest stands of medium age and lower in younger and older forests has been found in previous studies /Pregitzer and Euskirchen 2004/. The same tendency could also be seen in modelled soil respiration (Figure 7-8), although it was not very clear, especially in Laxemar-Simpevarp. According to /Janssens et al. 2001/and /Högberg et al. 2001/, NPP is the main factor determining soil respiration. A possible reason for the small differences in soil respiration at different ages for a forest stand in Laxemar-Simpevarp could be the small difference between peak NPP and NPP at equilibrium.

Litter and soil organic carbon pool

The large litter pool during the first year was a result of the large input directly after clear-cutting, and the subsequent decline in this pool was a result of heterotrophic decomposition. The litter pool was back at the same level as before clear-cutting after only 17 years. Several studies have shown that the SOC pool increases temporarily after harvesting /Black and Harden 1995, Pennock and van Knessel 1997, Johnson and Curtis 2001/, as was also seen during the first 9 years in the modelled output. After that, the 100-year continuous decline in SOC was probably an effect of a lower input of litter as a fraction of NPP, due to a high accumulation of biomass during these years. A general trend should be that the SOC pool reaches equilibrium after a while and returns to the same level as before the harvest /Johnson and Curtis 2001/. This was also seen in Forsmark, whereas in Laxemar-Simpevarp the level was slightly lower than before clear-cutting. Several scenarios are widespread in the literature. /Black and Harden 1995/ hypothesized that the continuous decrease in the SOC pool for a forest in California was due to lower C/N ratios. In a review of world forests, /Pregitzer and Euskirschen 2004/ described a continuous increase in the SOC pool.

7.4.6 Temporal variation in carbon balances for agricultural areas

The simulations for the agricultural areas were simplified. Crop management was not included in the model, and the only factors that distinguished crops from C_3 grass were the root to leaf ratio and the fact that no roots survived the winter. An improvement would be to include crop management, climate-dependent sowing and harvesting periods and more species-specific parameterization for the crops used in the investigation areas.

Net primary production

Compared with a global NPP average of 344 gC m^{-2} y^{-1} for agricultural areas /Goudriaan et al. 2001/, NPP was accurately estimated by the model (395 in Forsmark and 399 in Laxemar-Simpevarp). Other studies have obtained similar values (375–425 gC m^{-2} y^{-1}) /Bolinder et al. 2007/. Several factors influence the variation in NPP. NPP is generally proportional to incoming radiation, but the relationship can be altered by factors such as temperature, limited water supply, pests and nutrients /Goudriaan et al. 2001/. The variations caused by climate factors and disturbances such as pests were included in the model estimates, whereas nutrient limitations were not. Shortage of nutrients, however, is very rare since fertilization is common practice in agricultural areas.

Yield

The yield estimates (185 gC m^{-2} y^{-1} for Forsmark and 178 gC m^{-2} y^{-1} for Laxemar-Simpevarp) were somewhat lower than in regional statistics for the period 1966–1996, which were 242±110 gC m^{-2} y^{-1} in Forsmark (Uppsala County) and 207±101 gC m^{-2} y^{-1} in Laxemar-Simpevarp (Kalmar County) (Data from *www.scb.se*, corrected by adding threshing loss and straw yield, see Section 4.1.2, and averaged for five different crops). The assumption of a 66% removal of total biomass as yield may be too low and more should be allocated to harvest. The standard deviation for the yield statistics was much higher (a factor of 4), probably because the statistics were based on five different crops.

Soil organic carbon

The SOC pool is strongly dependent on agricultural management and type of crop grown /West and Post 2002, Baker et al. 2007/. Most agricultural soil contains less SOC than its ecological potential, and SOC pools are depleted and not accumulated as in the model results /Lal 2007/. Accumulation or depletion of the soil is strongly dependent on management practices, such as conventional tillage or no-till farming, crop rotation, leaving crop residue mulch and fertilization /West and Post 2002, Lal 2007/. 33% of the biomass was left as crop residue mulch in the model, whereas the rest was removed as yield, explaining the accumulation of carbon in the SOC pool.

7.4.7 Conclusions

Unlike many other detailed models, requiring many input parameters, LPJ-GUESS simulates carbon and vegetation dynamics based on the local climate. Generally the model-simulated carbon balances acceptably well. Values were in the upper range for boreal forests but still not unrealistic in comparison with field data and literature values. Temporal variation in carbon balances was also estimated and was fairly similar to literature estimates. The model has a couple of limitations, and the limitation that probably had the greatest influence on the results for the investigation areas was that anthropogenic influences were not included. The investigation area consists of managed forests, and sites are prepared by for example chopping, ditching, thinning, competition control and fertilization. These factors should be included in the future development of the model. The estimated SOC pool may also be greatly overestimated due to the young soils at both sites. Remote sensing and dynamic vegetation modelling were combined to estimate spatial variation in NPP. Further improvements in this technique could be to refine the input by including more spatial information, such as soil character, forest structure and land use. Nevertheless, the model has provided a good description of carbon balances in both investigated areas, and carbon balances were estimated realistically in comparison with field estimates and the literature.

8 Pools and fluxes of matter on the catchment scale

8.1 Introduction

Descriptions of pools and fluxes of matter in a catchment are of increasing interest to the Environmental Impact Assessments describing flows and accumulations of bioavailable contaminants such as radionuclides /Kumblad 2004, Lindborg and Löfgren 2005, Naito et al. 2002/. The rationale for using the catchment scale is that transport of elements is mediated by water and the catchment will set the boundary for further transport and accumulation. In this chapter, carbon estimates are presented across a landscape mosaic of different vegetation types and management regimes using a geographical information system (GIS). The carbon estimates were based on a combination of field and model estimates of pools and fluxes previously described in Chapters 4, 6 and 7. Pools and fluxes of consumers, such as animals, birds, amphibians and reptiles were included, as well as fluxes to humans. Human use of the landscape was described and analyzed in three different ways: a regional generic case, a self-sustainable case and a case were all potential arable land was used as such.

A large data set is presented in this chapter for the purpose of supporting further calculations and discussions in the safety analysis of the two sites. Much of the data will therefore only be presented in tables and not be further discussed in this chapter. The descriptions of carbon will also underpin the mass balance calculations of a large number of other elements that are presented in Chapter 9.

8.2 The conceptual model describing pools and fluxes of organic matter on the catchment scale

The definition of and the rationale for the use of the different ecosystem compartments and fluxes of carbon follows the description presented in Chapter 5, but a number of pools and fluxes have been aggregated here in order to present an overview of pools and fluxes on the catchment scale (Figure 8-1). Net primary production (NPP) is treated as the sum of all vegetation. The biomass of the tree layer is divided into a green and a woody compartment. The field layer consists of both the field and the bottom layer, while the root compartment consists of both tree and field layer fine roots (Ø< 2 mm for trees and <10 mm for herbs and grasses). The regolith is divided into a humus and a mineral soil compartment. The humus compartment consists of both litter and humus layers. Heterotrophic respiration is soil respiration minus autotrophic root respiration. Litter production is the combined fluxes from litterfall and root litter production. Horizontal transport is the water-mediated transport of mainly dissolved organic carbon to streams and lakes.

8.3 Data and methods

8.3.1 The catchments

The catchments that were modelled in Forsmark and Laxemar-Simpevarp are shown in Figures 8-2 and 8-3 with regard to their spatial distribution. Table 8-1 and 8-2 Show differences with regard to major land use classes.

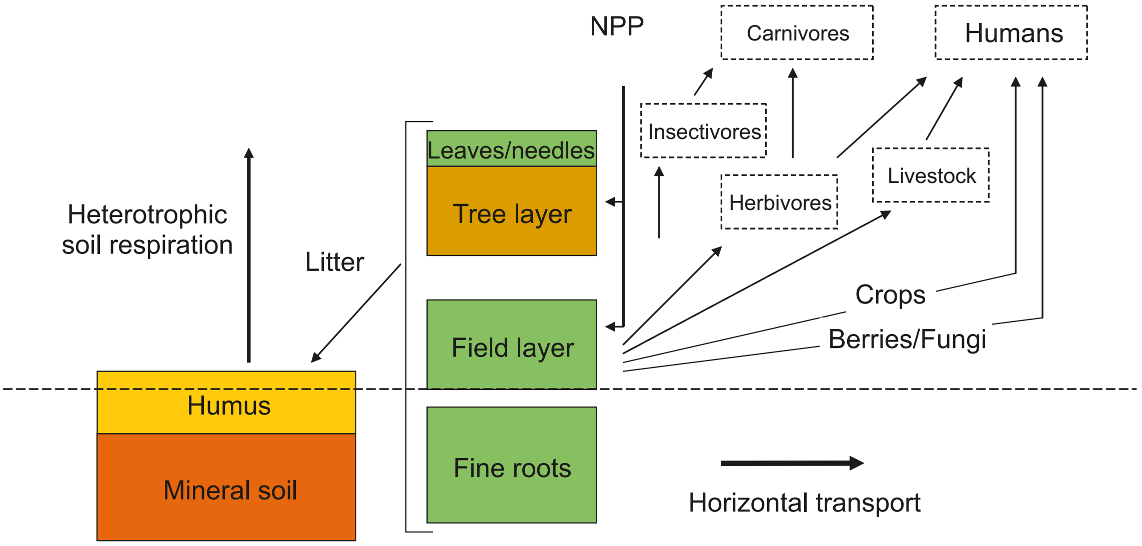


***Figure 8-1.** The different pools and fluxes describing the carbon balance on the catchment scale. Coloured boxes symbolize pools and arrows fluxes, while non-coloured boxes represent the consumers.*

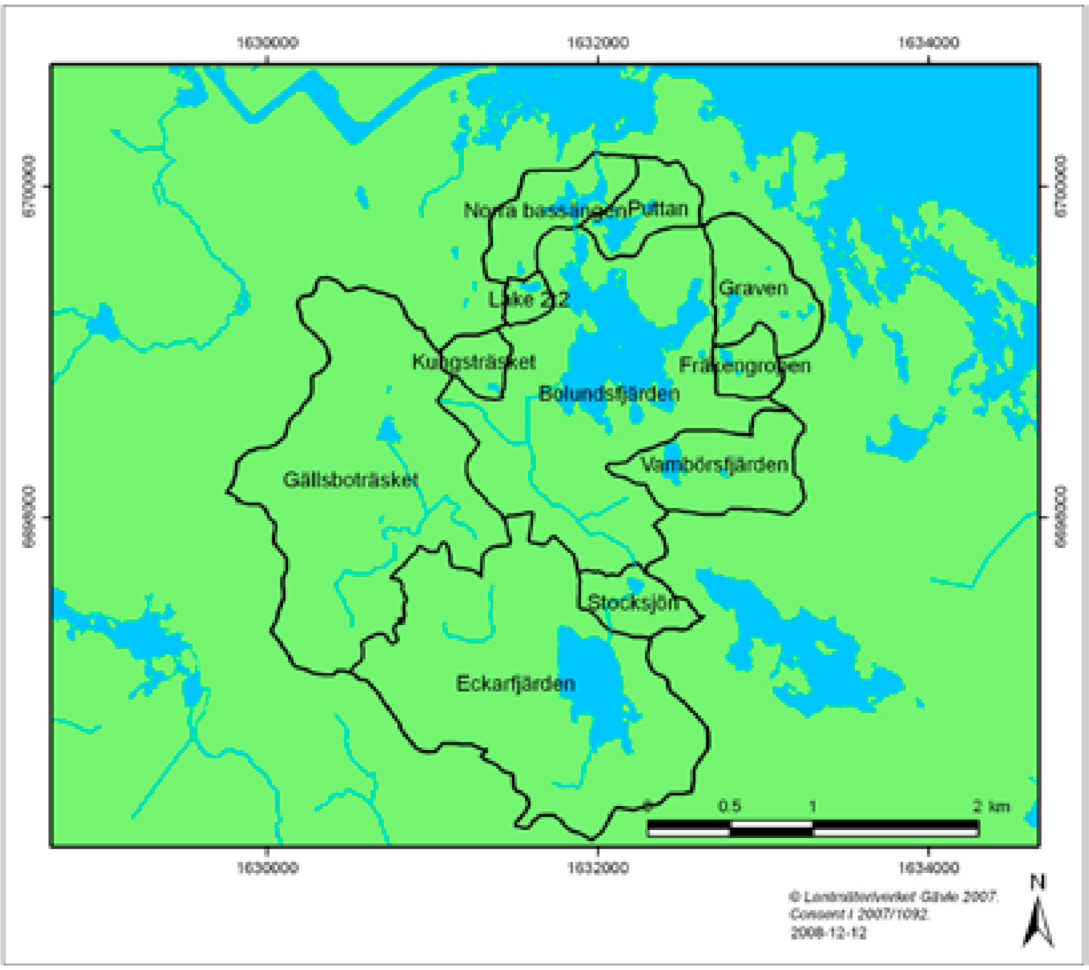
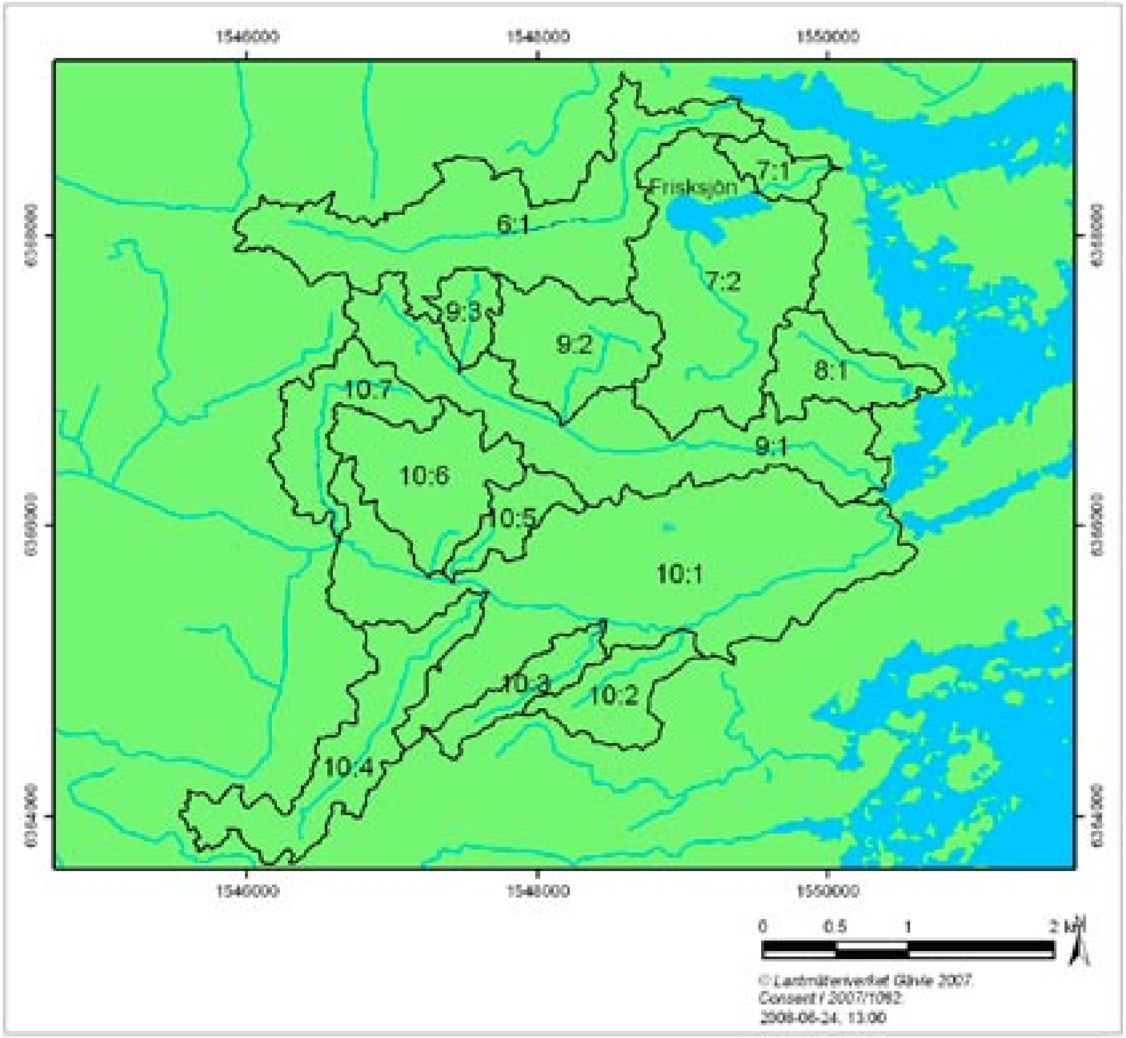


***Figure 8-2.** 2 catchment Forsmark with all 11 sub-catchments.*



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Consent I 2007/1092.
2008-06-24, 13:00

Figure 8-3. The 11 catchments modelled in the Laxemar-Simpevarp area. Catchment 10:1 continues to the left, but only the downstream area shown in the figure was modelled.

Table 8-1. The total areas of the catchments and the relative distributions (%) of some vegetation types in the modelled Forsmark catchments.

Catchment	Basin nr	Area (km²)	Forest	Forested wetland	Wetland	Arable land	Pasture	Clear-cut
Bolundsfjärden	136	1.84	69.6	2.2	17.9	0.0	0.0	10.3
Eckarfjärden	149	2.08	64.4	0.0	7.7	0.5	4.8	22.6
Fräkengropen	133	0.14	78.6	0.0	21.4	0.0	0.0	0.0
Gällsboträsk	142	2.13	40.8	0.5	11.3	0.0	0.5	46.9
Graven	127	0.38	63.2	0.8	26.3	0.0	0.0	7.9
Kungsträsket	131	0.12	58.3	0.0	5.0	0.0	0.0	33.3
Lake 2:2	128	0.07	71.4	0.0	7.1	0.0	0.0	28.6
Norra Bassängen	125	0.32	68.8	1.9	28.1	0.0	0.0	0.3
Puttan	124	0.22	59.1	0.0	36.4	0.0	0.0	2.3
Stocksjön	147	0.21	76.2	0.0	19.0	0.0	1.4	1.4
Varmbörsfjärden	141	0.46	78.3	2.2	19.6	0.0	0.0	2.2
Total		8.0	60.6	0.9	14.7	0.1	1.4	22.2

Table 8-2. The total areas of the catchments and the relative distributions (%) of some vegetation types in the modelled Laxemar-Simpevarp catchments.

Catchment	Basin nr	Area (km^2)	Forest	Forested wetland	Wetland	Arable land	Pasture	Clear-cut
6:1	502	2.00	75.5	0.1	0.0	12.0	5.0	7.5
7:1	502	0.21	85.7	0.0	5.7	0.0	0.0	11.4
7:2	507	1.74	84.5	0.3	1.2	6.3	2.1	6.3
8:1	508	0.50	90.0	0.0	3.2	0.0	1.4	3.6
9:1	508	1.85	69.7	0.0	0.2	10.8	5.9	13.0
9:2	508	0.77	71.4	0.0	0.0	14.3	0.3	13.0
9:3	508	0.22	63.6	0.0	0.0	17.3	3.2	18.2
10:1	508	3.44	65.4	1.3	0.5	6.4	6.7	19.5
10:2	508	0.46	69.6	0.0	1.3	11.1	3.5	14.3
10:3	508	0.32	84.4	0.0	0.0	7.5	2.5	6.3
10:4	508	1.00	73.0	0.7	0.0	15.0	3.9	8.3
10:5	508	0.29	48.3	1.4	0.0	4.5	2.1	41.4
10:6	508	0.89	76.4	0.3	0.0	3.6	3.1	16.9
10:7	508	0.61	86.9	0.0	0.0	3.0	2.5	8.2
Total		14.3	73.5	0.5	0.6	8.5	4.2	12.9

8.3.2 Description of vegetation types

Spatial delimitation of vegetation types

The vegetation types in the vegetation maps were re-classified into a more coarse-grained classification by merging grid code classes into new classes (Tables 8-3 and 8-4). Hard surfaces, mainly coastal rocks, were not assigned any values, due to low or absent biomass and NPP. There were no sea shores in the modelled catchments at the Forsmark and Laxemar-Simpevarp sites.

Identification and classification of wetlands in the interface zone between the terrestrial and aquatic environments

Near-shore areas identified as wetlands in the vegetation map (satellite images 25x25m resp. 30x30m, /Boresjö-Bronge and Wester 2003/) were overlain with the zero-DEM isoclines, showing the sea level, to distinguish between wetland habitats and the sea basin. Wetland parts falling below the zero-DEM isocline were included in the sea basin element budget. However, no sea shore wetlands were found within the modelled terrestrial catchments of Forsmark and Laxemar-Simpevarp.

The wetlands situated close to lakes were identified with the vegetation map. Lakes have been described in earlier work /Brunberg et al. 2004ab/, where the highest high water level was used to identify different kinds of habitats within the lake. One of these, called Littoral I, is defined as an area "with emergent and free-floating macrophytes, which is developed in shallow wind-sheltered areas with soft substrate". For the lakes in Forsmark, these areas were dominated by reed (*Phragmites australis*) and were classified as "open wetlands to lake". This also applied to Frisksjön in Laxemar-Simpevarp, which was the only lake within the modelled catchments.

Concerning accumulation and transport of radionuclides, an assumption of zero exchange between a wetland (reed belt) and the lake/sea has to be regarded as conservative as long as the wetland area is smaller than the lake area, since it concentrates the radionuclides into an area (the reed belt) smaller than the area of accumulation bottoms in adjacent sea basins. The potentially most important input of high-concentration contamination is contaminated groundwater discharging into the interface between land and lake/sea, or discharging higher up in the drainage areas, rather than directly into the sea water. This may, however, not be applicable to a wetland–lake interface, since radionuclides can reach much higher concentrations in the lake water than in the sea due to the generally smaller water volumes and longer water retention times in lakes.

Parameterization of the vegetation types

The identified vegetation types were parameterized using data from the LPJ-GUESS modelling (Tables 7-4 and 7-5). Wetlands were, however, difficult to model with LPJ-GUESS and therefore other sources of information had to be used in order to present carbon budgets for those ecosystems. In Forsmark, one Norway spruce wetland with alder was studied, whereas one alder near-shore wetland was studied in Laxemar-Simpevarp (see Section 6, SS1 and S1 in Table 6-10). These were used to describe the forested wetlands in both Forsmark and Laxemar-Simpevarp. The conifer wetland in Laxemar-Simpevarp is, however, dominated by Scots pine, but due to the small total area of this wetland type in Laxemar-Simpevarp, the Norway spruce wetland from Forsmark was used instead.

For the non-forested wetland types, mires and wetlands in connection with lakes, a number of sources were used including local measurements as well as literature data. Site-specific data describing biomass and NPP for both Forsmark and Laxemar-Simpevarp were available for the mires /Löfgren 2005/. Similarly, /Hedenström and Sohlenius 2008, Sohlenius and Hedenström 2008/ presented estimates of the soil carbon pools (see Tables 8-3 and 8-4). Accumulation in the SOC pool for mires was assumed to approximate the long-term accumulation in mires estimated by /Sternbeck et al. 2006/. Accordingly, heterotrophic respiration was calculated by substituting accumulation in the SOC from litter production. The reason for not using the estimated soil respiration from a mire in Laxemar-Simpevarp by /Tagesson 2007/ was because of difficulties in separating the soil respiration into its autotrophic and heterotrophic components. The vegetation type “wetland to lake”, which is a reed-dominated ecosystem, was assigned the biomass and above-ground (AG) NPP estimates from the sites (Table 4-6) /Andersson et al. 2003, Andersson et al. 2006/. Below-ground (BG) production was assumed to be 77% of the AG production /Asaeda and Karunaratne 2000/. By assuming that the annual root mortality was 7.5% /Asaeda and Karunaratne 2000/, AG mortality was 100%, 41% of the litter production was respired regardless whether it was produced AG or BG /Asaeda and Karunaratne 2000/ and the rest was transferred to the SOC pool, all fluxes could be calculated.

In the evaluation of the LPJ-GUESS results, the SOC was consistently found to be overestimated by the model. Site estimates of the litter pool were also added /Löfgren 2005/ and the calculations are described in Section 6.2.2. The humus and mineral soil carbon pools were from /Lundin et al. 2004 and 2005a/, which have partly been recalcultated, see /Hedenström and Sohlenius 2008, Table 6-32 Sohlenius and Hedenström 2008/. The conifer wetland was parameterized with a SOC pool from Forsmark when used for Forsmark and with a pool from Laxemar-Simpevarp when used for Laxemar-Simpevarp. The LPJ-GUESS estimates lacked a bottom layer, which may be rather significant in terms of biomass and NPP in boreal environments. A bottom layer were therefore added with regard to biomass /Löfgren 2005/. NPP for this layer was, however, not added to avoid interference with the climate-based descriptions of the fluxes. The resulting parameterization is presented in Table 8-3 for Forsmark and Table 8-4 for Laxemar-Simpevarp.

Implementation in a GIS

The ecosystems and their properties (Tables 8-3 and 8-4) were assigned grid codes in the vegetation map (column 2). This resulted in a map describing the spatial extent of each ecosystem and their different ecosystem properties. The catchments were individually cut out and the area of each vegetation type was multiplied by the area-specific property in Tables 8-3 and 8-4 and added to the result of each vegetation type and pool/flux within the catchment to generate an estimate for the whole catchment.

Table 8-3. Ecosystem properties for the vegetation types used to describe the terrestrial landscape in Forsmark in the GIS model. The grid codes in column 2 are defined in /Boresjö Bronge and Wester 2003/. Pools are in gC m^{-2} and fluxes are in gC m^{-2} y^{-1}.

Vegetation types	Grid code in Veg. map	Source	Tree layer				Field and bottom layer				SOC pool					Accumulation	
			Wood	Green	Roots	NPP	Green	Roots	Bottom layer	NPP	Litter	Humus	Min. soil	Het._ resp	Lit. prod.	Acc._ veg.	Acc._ SOC
Young Norway spruce	12,41,43	Spruce25[1]	3,997	222	222	628	13	26	62	37	544	2,921	4,586	355	428	177	103
Old Norway spruce	11	Spruce80[1]	8,702	194	194	564	14	28	62	39	544	2,921	4,586	404	594	–7	237
Young Scots pine	14,42	Pine25[1]	4,201	216	216	617	12	25	62	33	544	2,921	4,586	361	301	306	–19
Old Scots pine	13	Pine80[1]	8,201	173	173	570	7	15	62	17	544	2,921	4,586	398	337	246	48
Scots pine on bedrock	15	Dry pine[1]	8,458	181	182	586	2	4	213	4	544	831	732	452	326	261	–121
Old deciduous forest	21,23,26	Deciduous[1]	6,379	61	61	456	3	6	26	6	506	0	13,554	298	284	172	3
Mixed forest	30	Mixed[1]	7,017	128	128	505	11	22	26	29	506	0	13,554	358	370	158	25
Clear cut	46,50,64	Clear-cut[1]	87	9	9	70	146	291	62	428	544	2,921	4,586	571	242	245	–321
Clear-cut with birch (young deciduous)	44,45,31	C-c birch[1]	1,821	67	67	497	15	29	62	38	544	2,921	4,586	347	394	134	70
Pasture	82	Pasture[1]	0	0	0	0	176	353	23	477	459	0	13,884	327	444	33	117
Arable land	81	Agri[1]	0	0	0	0	361	69	0	584	0	0	13,884	439	584	0	0
Forested wetland, conifers	61, 62	SS1 (Fm)[2]	5,411	326	166	404	46	22	0	25	383	2,594	3,367	225	299	130	74
Forested wetland, deciduous	63	S1 (Sm)[2]	6,035	97	41	314	15	38	0	46	507	2,594	3,367	365	202	158	–163
Open wetland	64, 72, 74–79	Mire[3]	0	0	0	0	399	1,787	0	253	252	43,282	0	215	253	0	38
Open wetland to lake	See text	Lake shore[3]	0	0	0	0	187	623	0	331	252	43,282	0	81	198	133	117

1) LPJ-GUESS data from Section 7. 2) Field-estimated data from Section 6. 3) Field-estimated data from Section 4. 4) Is not found among the catchments that are described below.

Table 8-4. Ecosystem properties for the vegetation types used to describe the terrestrial landscape in Laxemar-Simpevarp in the GIS model. The grid codes in column 2 are defined in /Boresjö Bronge and Wester 2004/. Pools are in gC m^{-2} and fluxes are in gC m^{-2} y^{-1}.

Vegetation types	Grid code in Veg. map	Source	Tree layer				Field and bottom layer				SOC pool					Accumulation	
			Wood	Green	Roots	NPP	Green	Roots	Bottom layer	NPP	Litter	Humus	Min. soil	Het._ resp	Lit._prod	Acc._ veg.	Acc._ SOC
Young Norway spruce	12,41,43	Spruce25[1]	3,912	212	213	566	10	20	62	25	775	4,820	3,420	297	354	210	67
Old Norway spruce	11	Spruce80[1]	8,340	195	196	543	9	19	62	25	775	4,820	3,420	346	346	–193	–1
Young Scots pine	14,42	Pine25[1]	4,377	208	208	561	8	15	62	25	775	4,820	3,420	281	371	196	122
Old Scots pine	13	Pine80[1]	8,163	159	160	466	9	18	62	25	775	4,820	3,420	375	744	–340	450
Scots pine on bedrock	15	Dry pine[1]	7,974	155	157	466	8	16	213	19	591	2,410	340	459	592	–119	162
Old deciduous forest	24,25	Deciduous[1]	5,958	62	63	410	8	16	26	25	238	0	9,540	290	312	10	29
Mixed forest	30	Mixed[1]	7,339	119	120	459	7	15	26	25	238	0	9,540	320	448	–101	133
Clear cut	50	Clear-cut[1]	99	10	10	74	120	246	62	25	775	4,820	3,420	532	257	148	–271
Clear-cut with birch (young deciduous)	23,44,45	C-c birch[1]	1,856	62	62	444	8	16	62	25	775	4,820	3,420	275	360	50	106
Pasture	82	Pasture[1]	–	–	–	–	288	281	23	371	236	0	27,600	308	379	–8	88
Arable land	81	Agri[1]	–	–	–	–	288	57	0	446	0	0	20,460	389	446	0	0
Forested wetland, conifers	62	SS1 (Fm)[2]	5,411	326	166	404	3	22	43	25	383	34,180	0	225	299	130	74
Forested wetland, deciduous	63	S1 (Sm)[2]	6,035	97	41	314	15	38	0	46	507	34,180	0	365	202	158	1
Open wetland	71–77, 79,80	Mire[3]	0	0	0	0	190	1,142	110	342	136	1,564	0	313	342	0	29
Open wetland to lake	78, littoral 1	Lake shore[3]	0	0	0	0	275	917	0	487	136	1,564	0	119	291	196	172

1) LPJ-GUESS data from Chapter 7. 2) Field-estimated data from Section 6. 3) Field-estimated data from Section 4. 4) Is not found among the catchments that are described below.

Export of carbon

The transport of total organic carbon in surface water was estimated from concomitant measurements of concentrations and discharge in streams of Forsmark, Appendix F in /Tröjbom et al. 2007/ and Laxemar-Simpevarp, Appendix C in /Tröjbom et al. 2008/.

Fungi and berry yield

The yield of fungi was assumed to be 0.122 gC m^2 y^{-1} (Table 4.56, see discussion in Section 4.3.2) in both Forsmark and Laxemar-Simpevarp. This yield was assigned to all forest types, clear-cuts and grasslands, excluding open wetlands and arable land.

Berry yield was estimated using the information presented in Section 4.3.2 and comprises the following species: bilberry, lingonberry, raspberry, rosehip, cloudberry and cranberry.

8.3.3 Description of consumers

The description of the food web is similar to the one in Sections 4.2.1 to 4.2.3 and is based on the food web illustrated in Figure 4-29. The carbon pools and fluxes were calculated for four functional groups – herbivores, insectivores, carnivores and livestock – in 11 drainage areas in Forsmark and 14 in Laxemar-Simpevarp. Spatial distribution of mammals, birds, amphibians and reptiles followed the distributions presented in Sections 4.2.1–4.2.3. The calculations were based on the general figures per unit area and the habitat selection for each species given in Tables 4-31, 4-32, 4-38 and 4-41 and 4-43, 4-44 and the land use distribution within each site obtained from the vegetation map (see Sections 3.1.2 and 3.2.2).

Distribution of livestock in the landscape

The domestic animals in Forsmark are cattle and sheep, while there are cattle, sheep and pigs in Laxemar-Simpevarp. Two different cases were calculated concerning livestock density and production of beef and milk. Firstly, a regional generic case was calculated based on meat production in Forsmark parish and the Laxemar-Simpevarp area, assuming a certain amount of imported fodder (Table 4-31 and 4-32). Secondly, a potential self-sustainable case was calculated where the livestock density was set by the potential area that can sustain the livestock with fodder production and grazing.

Potential self-sustainable case

To calculate the self-sustainable case some assumptions have to be made. Available agricultural land includes both arable land (crop land) and grazed pastures (grazing land). The agricultural land, directly used for agricultural production, is also referred to as direct land area. In order for the food production system to work, more agricultural area is needed than the actual agricultural land where the food is produced. This agricultural land that is not directly used for agricultural production is called semi-direct area /Johansson 2005/.

/Johansson 2005/ has calculated the direct area (DA) for producing food consumed in Sweden for the period 1997–2000 using the following equation: DA = D + I – E, where D is the domestic area, I is the imported area and E is the exported area. The domestic area (D) producing food was 2.67 million ha in Sweden for the period 1997–2000. The imported area (I) was 1.86 million ha. The exported area (E), which to some extent is imported area, e.g. area for coffee and oil-bearing crops that are re-exported, was 0.79 million ha. This gives a DA of 3.74 million ha. Together with the semi-direct land, estimated to be 261,744 ha in /Johansson 2005/, the total agricultural area comprises 4 million ha, or 0.44 ha per capita. The most dominant food area was that of fodder production, corresponding to 74% of Swedish DA. When calculating the potential production of crop and meat in the future, 74% of the agricultural area is assumed to be used for fodder production and grazing and 26% for crop production for human consumption. It is possible to estimate a potential self-sustainable case for each drainage area, based on the assumption that 74% of the agricultural area is used for fodder production and grazing and 26% for crop production for human consumption.

According to /Arnesson 2001/ a cow needs approximately 2.4 hectares for fodder production and grazing for its survival. This gives a density of 41.7 cows per km^2. One dairy cow can produce 7,735 kg of milk per year (2002). The cow gives birth to her first calf at the age of two years. Thereafter she has a calf each year and gives milk for ten months a year. An average dairy cow is slaughtered at the age of five years after she has given birth to three calves /Miliander et al. 2004ab/. Accordingly, five cows, 0–5 years old, can together produce three calves per year. Hence, three cows of five can produce milk. The milk production per unit area has been estimated using the following formula:

$\mathrm{Pmilk} = \rho \times 3/5 \times 7{,}735$

where ρ is the cattle density of 41.7 cows per km^2.

The total milk production in each catchment can be estimated based on the agricultural area. A steady population of five cows, 0–5 years old, which produces three calves per year, would have to keep one calf per year for breeding, which leaves two for slaughter together with the oldest cow. When calculating the theoretical meat production per unit area the following formula has been used:

$\mathrm{Pmeat} = 1/5 \times \rho \times \mathrm{Xcow} + 2/5 \times \rho \times \mathrm{Xcalf}$

where X is the biomass (live weight) and ρ is the cattle density of 41.7 cows per km^2.

The average weight of slaughtered cows and calves and the conversion factors between carcass weight and utilized carcass weight is calculated in /Miliander et al. 2004ab/. The carbon content of milk can be estimated from the content of proteins, carbohydrates and lipids /Altman and Dittmer 1964, Dyson 1978, Rouwenhorst et al. 1991/ (see Section 4.1.2).

Human consumption

The human consumption of crops (barley) and animal products (beef, milk and game meat) originating from the 11 catchment areas in Forsmark and 14 in Laxemar-Simpevarp was calculated using three different cases regarding consumption of agricultural products: a regional generic case, a potential self-sustainable case and crop production alone.

Human consumption of crops

Barley is the dominant crop in Forsmark and Misterhult parish /Miliander et al. 2004ab/ and human consumption is assumed to be equal to the standard yield of barley in the yield survey district (SKO area 0322 for Forsmark and SKO area 0814 for Laxemar-Simpevarp, Table 4-11). The standard yield is the yield of crops that are gathered during the harvest (straw yield and threshing loss excluded).

Production in each drainage area has been estimated by multiplying the standard yield by the estimated area for crop production.

According to Table 4-9, only 16% of the arable land in the Forsmark parish is used for production of crops for human consumption. This figure has been applied to the catchment areas in the regional generic case. Only one catchment area (Eckarfjärden) contained some arable land. According to Table 4-10, 21% of the arable land in Laxemar-Simpevarp is used for production of crops for human consumption.

In the self-sustainable case, 26% of the agriculture area is used for crop production, and in the third case, 100% of the agriculture area is used for crop production.

The amount of carbon in barley is estimated to be 0.46 gC gdw^{-1}, the same as for the field layer in /Fridriksson and Öhr 2003/. The dry weight is 86% of the fresh weight /SCB 2007/.

Human consumption of domestic meat

Consumption of beef has been estimated for each catchment area based on the meat production in Forsmark parish and the Laxemar-Simpevarp area (Tables 4-12 and 4-13) and the area for fodder production and grazing in each catchment area. For the regional generic case the area corresponds to 93.3% of the field area in Forsmark and 86.5% in Laxemar-Simpevarp (see Section 4.1.2). In the self-sustainable case, 74% of the field area is used for fodder production and grazing.

Human consumption of game meat

The species hunted for consumption are moose, roe deer and hare. The average harvests of these species in the local hunting zones of Forsmark and Misterhult parish /Miliander et al. 2004ab/ were applied to the catchment areas of Forsmark and Laxemar-Simpevarp (Tables 8-6 and 8-7). Human consumption (utilized carcass weights) is assumed to be 80% of the carcass weight, and the carcass weight is assumed to be 55% of the live weight (G Cederlund 2004, pers. comm.) The local carcass weights for moose are given in /Cederlund and Lemel 2007ab/, which give carcass weights for 2002–2006. The live weight of roe deer and hare are obtained from /Truvé and Cederlund 2005/.

Table 8-5. Hunting statistics describing the carbon flux from wildlife to humans in Forsmark.

Harvested species	Habitat	Harvest ind*km^{-2} (mean ± SD)	Biomass mgC m^{-2} y^{-1} (mean ± SD)	Carcass biomass mgC m^{-2} y^{-1} (mean ± SD)	Utilized biomass mgC m^{-2} y^{-1} (mean ± SD)
Moose[1]	Field +Forest	0.53 (± 0.08)	13.5 (± 1.97)	7.4 (± 1.09)	5.9 (± 0.87)
Roe deer[2]	Field +Forest	1.91 (± 0.53)	5.6 (± 1.54)	3.1 (± 0.85)	2.5 (± 0.68)
European hare[2]	Field	0.28 (± 0.13)	0.13 (± 0.06)	0.069 (± 0.03)	0.055 (± 0.02)
Mountaine hare[2]	Forest	0.13 (± 0.15)	0.05 (± 0.05)	0.02 (± 0.03)	0.02 (± 0.02)

[1] Harvest data for 1999-2003, from the County administrative board

[2] Harvest data for 1997-2001, from the National Association of Huntsmen

Table 8-6. Hunting statistics describing carbon flux from wildlife to humans in Laxemar-Simpevarp.

Harvested species	Habitat	Harvest ind*km^{-2} (mean ± SD)	Biomass mgC m^{-2} y^{-1} (mean ± SD)	Carcass biomass mgC m^{-2} y^{-1} (mean ± SD)	Utilized biomass mgC m^{-2} y^{-1} (mean ± SD)
Moose[1]	Field +Forest	0.48 (± 0.10)	11.5 (± 2.5)	6.3 (± 1.4)	5.1 (± 1.1)
Roe deer[2]	Field +Forest	2.15 (± 0.99)	6.3 (± 2.9)	3.5 (± 1.6)	2.8 (± 1.3)
European hare[2]	Field	0.29 (± 0.11)	0.13 (± 0.05)	0.07 (± 0.03)	0.06 (± 0.02)
Mountain hare[2]	Forest	0.1 (± 0.07)	0.04 (± 0.03)	0.02 (± 0.01)	0.02 (± 0.01)

[1] Harvest data for 1997-2003, from the County administrative board

[2] Harvest data for 1997-2001, from the National Association of Huntsmen

8.4 Results

8.4.1 Vegetation and regolith

The calculated pools and fluxes for the vegetation and regolith pools are presented in Tables 8-7 and 8-8.

8.4.2 Food web

The calculated pools and fluxes within the food web at both sites are presented in Tables 8-9 and 8-10. Birds are shown separately and contribute a significant share to both biomass and consumption in all catchments (Tables 8-11, 8-12), where the ratio between birds and other animals (excluding livestock) in Forsmark was 5% and 81% for biomass and consumption, respectively. The corresponding figures for Laxemar-Simpevarp were 4% and 48%. Pools and fluxes for domestic animals are presented in Tables 8-13 and 8-14 for a generic and a self-sustainable case.

Tabell 8-7. Pools and fluxes for vegetation and soil in Forsmark. Pools are in gC and fluxes gC y^{-1}.

		Bolunds-fjärden	Eckar-fjärden	Fräken-gropen	Gällsbo-träsk	Graven	Kungs-träsket	Lake 2:2	Norra Bassängen	Puttan	Stocksjön	Varmbörs-fjärden
Tree layer	WOOD	9.76E+09	1.06E+10	9.22E+08	7.47E+09	1.56E+09	5.52E+08	3.37E+08	1.45E+09	1.04E+09	1.26E+09	2.58E+09
	GREEN	2.64E+08	2.72E+08	2.04E+07	2.31E+08	5.12E+07	1.69E+07	1.04E+07	4.19E+07	2.51E+07	2.84E+07	7.34E+07
	ROOTS	2.58E+08	2.68E+08	2.04E+07	2.29E+08	5.07E+07	1.69E+07	1.04E+07	3.94E+07	2.51E+07	2.84E+07	7.14E+07
Field layer	F_GREEN	7.48E+07	8.18E+07	5.37E+06	8.06E+07	1.81E+07	2.46E+06	1.76E+06	1.48E+07	1.45E+07	8.65E+06	1.67E+07
	F_ROOTS	4.02E+08	2.71E+08	2.93E+07	2.97E+08	1.43E+08	8.62E+06	4.80E+06	1.10E+08	8.11E+07	3.99E+07	1.30E+08
	Bottom layer	1.02E+08	1.19E+08	6.85E+06	1.01E+08	2.77E+07	5.62E+06	2.84E+06	2.47E+07	1.37E+07	1.03E+07	3.11E+07
Total biomass pool		1.09E+10	1.16E+10	1.00E+09	8.41E+09	1.85E+09	6.03E+08	3.67E+08	1.69E+09	1.20E+09	1.37E+09	2.90E+09
Soil organic carbon pool	SOC humus	1.93E+10	1.25E+10	1.47E+09	1.66E+10	5.38E+09	6.62E+08	4.31E+08	4.52E+09	3.90E+09	2.26E+09	4.96E+09
	SOCmin	7.62E+09	1.09E+10	6.23E+08	9.10E+09	1.34E+09	5.36E+08	2.71E+08	1.53E+09	7.94E+08	8.81E+08	1.88E+09
	Litter prod	7.35E+08	7.93E+08	6.34E+07	7.90E+08	1.50E+08	4.82E+07	2.94E+07	1.15E+08	8.57E+07	7.38E+07	1.93E+08
	Resp.	6.26E+08	7.65E+08	4.73E+07	7.42E+08	1.21E+08	4.35E+07	2.35E+07	9.61E+07	6.38E+07	6.90E+07	1.61E+08
NPP	Total	9.92E+08	1.15E+09	7.39E+07	1.15E+09	1.99E+08	6.97E+07	3.87E+07	1.61E+08	1.07E+0.8	1.09E+08	2.53E+08
NEP		4.09E+08	4.47E+08	3.08E+07	4.50E+08	7.96E+07	2.91E+07	1.59E+07	6.78E+07	4.69E+07	5.10E+07	1.02E+08
	Acc. veg.	2.28E+08	3.25E+08	8.92E+06	3.32E+08	4.03E+07	1.93E+07	7.71E+06	4.02E+07	1.91E+07	3.39E+07	5.10E+07
	Acc. SOC	1.82E+08	1.22E+08	2.19E+07	1.19E+08	3.93E+07	9.74E+06	8.20E+06	2.77E+07	2.78E+07	1.71E+07	5.05E+07
Export	TOC*	5.56E+06	5.06E+06	4.12E+05	5.91E+06	1.33E+06	2.92E+05	1.43E+05	1.07E+05	7.74E+05	6.50E+05	1.47E+06

*Diffuse transport per catchment from /Tröjbom et al. 2007/.

Tabell 8-8. Pools and fluxes for vegetation and soil in Laxemar-Simpevarp. Pools are in gC and fluxes gC y^{-1}.

		6:1	**7:1**	**7:2**	**8:1**	**9:1**	**9:2**	**9:3**	**10:1**	**10:2**	**10:3**	**10:4**	**10:5**	**10:6**	**10:7**
Tree layer	WOOD	1.06E+10	1.02E+09	1.02E+10	3.53E+09	9.37E+09	3.88E+09	1.03E+09	2.50E+10	2.32E+09	2.00E+09	5.25E+09	1.02E+09	4.67E+09	3.64E+09
	GREEN	2.66E+08	3.46E+07	2.53E+08	7.34E+07	2.17E+08	9.83E+07	2.27E+07	3.87E+08	5.57E+07	4.39E+07	1.20E+08	3.21E+07	1.20E+08	9.11E+07
	T_ROOTS	2.67E+08	3.46E+07	2.54E+08	7.39E+07	2.19E+08	9.89E+07	2.28E+07	3.86E+08	5.60E+07	4.41E+07	1.20E+08	3.20E+07	1.20E+08	9.16E+07
Field layer	F_GREEN	1.14E+08	4.06E+06	6.44E+07	1.10E+07	1.12E+08	4.16E+07	1.86E+07	1.80E+08	2.38E+07	1.20E+07	6.43E+07	9.19E+06	2.66E+07	1.43E+07
	F_ROOTS	7.52E+07	1.72E+07	7.29E+07	3.24E+07	9.05E+07	2.48E+07	1.54E+07	1.93E+08	2.11E+07	9.52E+06	4.16E+07	1.00E+07	2.86E+07	1.49E+07
	Bottom layer	1.19E+08	1.51E+07	1.20E+08	3.87E+07	1.07E+08	5.13E+07	1.29E+07	1.68E+08	2.69E+07	1.85E+07	5.43E+07	1.53E+07	4.96E+07	4.18E+07
Total biomass pool		1.14E+10	1.13E+09	1.10E+10	3.76E+09	1.01E+10	4.19E+09	1.12E+09	2.63E+10	2.50E+09	2.13E+09	5.65E+09	1.12E+09	5.02E+09	3.89E+09
Soil organic carbon pool	SOC humus	7.81E+09	1.08E+09	7.55E+09	2.40E+09	6.76E+09	3.08E+09	8.37E+08	1.33E+10	1.80E+09	1.60E+09	5.17E+09	1.66E+09	4.84E+09	2.63E+09
	SOCmin	1.43E+10	7.62E+08	9.07E+09	1.77E+09	1.37E+10	4.70E+09	1.65E+09	2.58E+10	3.08E+09	1.97E+09	7.75E+09	1.60E+09	5.24E+09	3.07E+09
	Litter prod.	9.96E+08	9.08E+07	9.32E+08	3.19E+08	9.34E+08	3.90E+08	1.14E+08	1.49E+09	2.34E+08	1.77E+08	5.11E+08	1.13E+08	4.19E+08	3.17E+08
	Resp.	6.92E+08	5.90E+07	6.03E+08	1.76E+08	6.51E+08	2.75E+08	8.70E+07	1.11E+09	1.52E+08	1.13E+08	3.52E+08	8.72E+07	2.92E+08	2.07E+08
NPP	Total	1.00E+09	1.14E+08	8.68E+08	2.37E+08	8.73E+08	3.75E+08	9.43E+07	1.62E+09	2.26E+08	1.58E+08	4.78E+08	1.40E+08	4.42E+08	3.11E+08
NEP		2.02E+08	4.00E+07	2.28E+08	5.10E+07	1.77E+08	8.23E+07	1.17E+07	3.44E+08	5.46E+07	2.82E+07	8.87E+07	4.33E+07	1.09E+08	8.22E+07
	Acc. veg.	-1.48E+08	1.16E+07	-1.56E+08	-1.12E+08	-1.54E+08	-5.06E+07	-2.06E+07	-6.01E+07	-3.69E+07	-4.74E+07	-9.08E+07	1.52E+07	-4.01E+07	-4.97E+07
	Acc. SOC	3.50E+08	2.84E+07	3.83E+08	1.63E+08	3.31E+08	1.33E+08	3.22E+07	4.04E+08	9.15E+07	7.55E+07	1.79E+08	2.81E+07	1.49E+08	1.32E+08
Export	Export TOC1)	9.58E+06	1.02E+06	8.27E+06	2.37E+06	8.82E+06	3.67E+06	1.06E+06	1.64E+072)	2.20E+06	1.53E+06	4.78E+06	1.39E+06	4.25E+06	2.91E+06

1) Diffuse transport per catchment from /Tröjbom et al. 2008/; 2) The export amount was calculated using the figure 4,770 gC km^{-2} obtained from /Tröjbom et al. 2008/ and the size of the cut out 10_1.

Table 8-9. Carbon pools and fluxes in a regional generic case for the functional groups herbivores, insectivores and carnivores in 11 catchment areas in Forsmark. Biomasses are in gC and, consumption and production are in gC y^{-1}.

Total gC/y **”Regional generic case”**		**Vambors-fjärden**	**Fräkengropen**	**Stocksjön**	**Bolunds-fjärden**	**Gällsbo-träsket**	**Eckarfjärden**	**Lake 2:2**	**Kungsträsket**	**Norra Bassängen**	**Graven**	**Puttan**
Herbivores	Biomass	27,531	8,121	12,145	109,339	126,541	123,146	3,952	7,237	18,817	22,445	12,990
	Consumption	623,091	184,347	278,837	2,564,668	2,878,393	2,780,726	92,108	166,302	435,881	509,360	300,066
	Production	9,537	2,818	4,238	38,578	43,957	42,617	1,390	2,527	6,595	7,785	4,545
Domestic animals	Biomass	0	0	11,047	0	46,675	404,796	0	0	0	0	0
(Cattle + sheep)	Consumption	0	0	407,260	0	1,720,694	14,923,104	0	0	0	0	0
	Production	0	0	3,753	0	15,855	137,508	0	0	0	0	0
Carnivores	Biomass	2,815	830	1,239	11,140	12,969	12,624	767	743	1,912	2,287	1,316
	Consumption	35,791	10,546	15,691	141,670	166,337	161,648	5,216	9,607	24,003	28,735	16,317
	Production	2,390	705	1,051	9,457	11,026	10,729	344	632	1,620	1,937	1,112
Insectivores	Biomass	11,890	3,599	5,363	47,330	45,030	46,837	1,899	3,414	8,974	10,208	6,063
	Consumption	96,862	28,888	43,102	384,328	411,738	411,355	14,557	26,453	69,106	80,768	47,251
	Production	6,566	1,962	2,927	26,066	27,504	27,616	995	1,806	4,722	5,497	3,223

Table 8-10. Carbon pools and fluxes in a regional generic case for the functional groups herbivores, insectivores and carnivores in 14 catchment areas in Laxemar-Simpevarp. Biomasses are in gC and, consumption and production are in gC y^{-1}.

Total gC/y ”Regional generic case”		Area 6:1	Area 7:1	Area 7:2	Area 8:1	Area 9:1	Area 9:2	Area 9:3	Area 10:1	Area 10:2	Area 10:3	Area 10:4	Area 10:5	Area 10:6	Area 10:7
Herbivores	Biomass	122,428	13,035	106,240	30,215	112,823	46,854	13,599	209,975	28,125	19,569	61,231	17,707	54,155	37,220
	Consumption	3,641,450	392,345	3,148,893	901,305	3,367,964	1,388,500	410,633	6,207,004	838,844	596,594	1,828,712	526,541	1,582,897	1,120,188
	Production	48,232	5,166	41,736	11,909	44,543	18,415	5,407	82,394	11,097	7,818	24,185	6,968	21,095	14,749
Domestic animals (Cattle, sheep, pig)	Biomass	1,054,175	0	433,646	26,022	978,416	329,756	136,105	1,471,229	205,745	97,930	564,328	59,589	194,525	105,717
	Consumption	59,566,585	0	24,503,350	1,470,367	55,285,811	18,633,011	7,690,657	83,132,375	11,625,709	5,533,552	31,887,563	3,367,094	10,991,735	5,973,554
	Production	556,486	0	228,916	13,737	516,494	174,074	71,848	776,643	108,610	51,696	297,902	31,456	102,688	55,806
Carnivores	Biomass	11,775	1,254	10,236	2,911	10,845	4,510	1,304	20,223	2,704	1,878	5,884	1,706	5,230	3,581
	Consumption	166,378	17,742	144,768	41,188	153,245	63,745	18,422	285,878	38,217	26,553	83,125	24,137	73,993	50,664
	Production	12,364	1,317	10,750	3,057	11,388	4,736	1,370	21,238	2,840	1,972	6,178	1,792	5,493	3,761
Insectivores	Biomass	37,836	4,912	35,583	9,838	35,045	14,316	4,141	67,826	8,594	6,002	18,679	5,414	16,597	11,362
	Consumption	428,773	49,951	385,798	108,332	395,879	163,370	47,254	750,229	98,010	68,209	213,159	61,782	189,398	129,657
	Production	30,782	3,621	27,805	7,797	28,429	11,722	3,390	53,974	7,032	4,896	15,294	4,433	13,589	9,303

Table 8-11. Carbon pools and fluxes for birds for the 11 catchment areas in Forsmark in gC for biomass and in gC y^{-1} for consumption.

Birds		Vambors-fjärden	Fräken-gropen	Stocksjön	Bolunds-fjärden	Gällsbo-träsket	Eckar-fjärden	Lake 2:2	Kungs-träsket	Norra Bassängen	Graven	Puttan
Herbivores+omnivores	Biomass	1.16E+04	3.41E+03	5.06E+03	4.58E+04	5.40E+04	5.24E+04	1.70E+03	3.13E+03	7.70E+03	9.23E+03	5.20E+03
	Consumption	4.08E+05	1.20E+05	1.76E+05	1.62E+06	1.97E+06	1.90E+06	6.29E+04	1.17E+05	2.59E+05	3.11E+05	1.66E+05
Insectivores	Biomass	6.11E+03	1.80E+03	2.64E+03	2.42E+04	2.95E+04	2.85E+04	9.45E+02	1.76E+03	3.87E+03	4.66E+03	2.48E+03
	Consumption	1.99E+05	5.83E+04	8.52E+04	7.87E+05	9.70E+05	9.34E+05	3.13E+04	5.86E+04	1.23E+05	1.49E+05	7.73E+04
Carnivores	Biomass	8.43E+02	2.48E+02	3.66E+02	3.34E+03	4.02E+03	3.89E+03	1.28E+02	2.37E+02	5.45E+02	6.55E+02	3.57E+02
	Consumption	1.53E+04	4.51E+03	6.69E+03	6.06E+04	7.19E+04	6.97E+04	2.27E+03	4.19E+03	1.01E+04	1.21E+04	6.78E+03

Table 8-12. Carbon pools and fluxes for birds for the 14 catchment areas in Laxemar-Simpevarp in gC for biomass and in gC y^{-1} for consumption.

Birds		Area 6:1	Area 7:1	Area 7:2	Area 8:1	Area 9:1	Area 9:2	Area 9:3	Area 10:1	Area 10:2	Area 10:3	Area 10:4	Area 10:5	Area 10:6	Area 10:7
Herbivores +omnivores	Biomass	4.41E+04	4.41E+03	3.68E+04	1.02E+04	4.07E+04	1.67E+04	4.98E+03	7.44E+04	1.01E+04	6.77E+03	2.22E+04	6.03E+03	1.85E+04	1.26E+04
	Consumption	1.39E+06	1.45E+05	1.19E+06	3.35E+05	1.28E+06	5.30E+05	1.55E+05	2.37E+06	3.18E+05	2.18E+05	6.96E+05	1.97E+05	6.05E+05	4.13E+05
Insectivores	Biomass	1.90E+04	2.10E+03	1.69E+04	4.88E+03	1.75E+04	7.33E+03	2.08E+03	3.30E+04	4.38E+03	3.10E+03	9.46E+03	2.84E+03	8.72E+03	5.99E+03
	Consumption	6.07E+05	6.93E+04	5.53E+05	1.62E+05	5.59E+05	2.36E+05	6.57E+04	1.07E+06	1.40E+05	1.01E+05	3.00E+05	9.38E+04	2.87E+05	1.98E+05
Carnivores	Biomass	2.34E+03	2.25E+02	1.90E+03	5.18E+02	2.16E+03	8.81E+02	2.67E+02	3.91E+03	5.34E+02	3.51E+02	1.19E+03	3.09E+02	9.49E+02	6.42E+02
	Consumption	5.06E+04	4.49E+03	3.91E+04	1.03E+04	4.66E+04	1.88E+04	5.89E+03	8.26E+04	1.15E+04	7.24E+03	2.59E+04	6.22E+03	1.91E+04	1.28E+04

Table 8-13. Carbon pools and fluxes calculated for two cases: a regional generic and a potential self-sustainable case for the functional group "Domestic animals" in 11 catchment areas in Forsmark. Biomass in gC and, consumption and production in gC y^{-1}.

"Regional generic case"		Vamborsfjärden	Fräken-gropen	Stocksjön	Bolunds-fjärden	Gällsbo-träsket	Eckarfjärden	Lake 2:2	Kungs-träsket	Norra Bassängen	Graven	Puttan
Livestock	Biomass	0	0	11,047	0	46,675	404 796	0	0	0	0	0
	Consumption	0	0	407,260	0	1,720,694	14 923 104	0	0	0	0	0
	Production	0	0	3,753	0	15 855	137 508	0	0	0	0	0
"Self-sustainable case"												
Livestock	Biomass	138,306	41,890	70,019	539,212	402,538	434,539	8,338	10,296	142,758	165,546	129,964
	Consumption	7,982,489	2,417,713	4,041,235	31,121,333	23,233,005	25,080,010	481,262	594,227	8,239,452	9,554,730	7,501,067
	Production	57,170	17,315	28,943	222,888	166,393	179,621	3,447	4,256	59,010	68,430	53,722

Table 8-14. Carbon pools and fluxes calculated for two cases: a regional generic and a potential self-sustainable case for the functional group "Domestic animals" in 14 catchment areas in Laxemar-Simpevarp. Biomass in gC and, consumption and production in gC y^{-1}.

"Regional generic case"		Area 6:1	Area 7:1	Area 7:2	Area 8:1	Area 9:1	Area 9:2	Area 9:3	Area 10:1	Area 10:2	Area 10:3	Area 10:4	Area 10:5	Area 10:6	Area 10:7
Livestock	Biomass	1,097,948	0	452,842	26,022	1,014,827	350,155	143,064	1,512,029	215,106	102,223	591,070	61,924	200,335	108,972
	Consumption	62,039,994	0	25,588,040	1,470,367	57,343,221	19,785,648	8,083,876	85,437,794	12,154,627	5,776,154	33,398,641	3,499,037	11,319,988	6,157,525
	Production	579,593	0	239,050	13,737	535,715	184,842	75,522	798,181	113,552	53,962	312,018	32,689	105,754	57,525
"Self-sustainable case"															
Livestock	Biomass	528,989	18,593	252,723	36,522	487,374	177,508	70,644	727,574	114,556	49,549	289,121	29,652	93,543	51,014
	Consumption	31,686,349	1,113,691	15,138,099	2,187,660	29,193,630	10,632,680	4,231,576	43,581,604	6,861,871	2,967,972	17,318,282	1,776,148	5,603,221	3,055,733
	Production	226,935	7,976	108,418	15,668	209,082	76,150	30,306	312,128	49,144	21,256	124,032	12,721	40,130	21,885

8.4.3 Human consumption

Human consumption of game meat and the three different cases describing the use of the agricultural land – the regional generic case, the self-sustainable case and 100% crop cultivation – are presented in tables 8-15 to 8-18.

8.4.4 Berry and fungi

Fungi and berry yields are presented in Tables 8-19 and 8-20. These yields have to be considered as the potential maximum yield, of which only a small fraction is utilized by humans. The fungi yield was consistently higher than the estimated berry yield for all catchments.

8.4.5 Summarizing models for the two sites

Figure 8-4 summarizes the above estimated and tabulated values for the modelled areas in Forsmark and Laxemar-Simpevarp.

8.5 Discussion

8.5.1 Vegetation and regolith

The range in the estimates of different properties is dependent on the size of the catchments and the spatial distribution of the different vegetation types, which in this landscape mainly consists of conifer forests. NPP is allocated among the different functional compartments of the autotrophic organisms, where a minor fraction is incorporated into perennial woody tissues, such as the stem in trees, and a large fraction enters the soil organic matter pool as litter within a year (e.g. Figure 8-4a). Interestingly, this pattern was not so obvious in Laxemar-Simpevarp where the LPJ-GUESS-modelled litter production was large for this year (Figure 8-4b) and exceeded heterotrophic soil respiration. This resulted in a net loss of biomass (66 gC m^{-2} y^{-1}) and a net accumulation of carbon (174 gC m^{-2} y^{-1}) in the SOC pool summed over all catchments. The corresponding figures for Forsmark were a net gain in biomass of 139 gC m^{-2} y^{-1} and a net accumulation of carbon in the SOC pool of 79 gC m^{-2} y^{-1}. The net loss of biomass in Laxemar-Simpevarp is mainly explained by the low precipitation during 2005 in comparison to longer time-series (Figure 2-11 /Werner et al. 2008/). A dry year increases both loss of biomass caused by fire and litterfall. Litterfall may be highly variable between years /Bray and Gorham 1964/ and a similar peak in litter production was recorded in Laxemar-Simpevarp during the storm “Gudrun” in 2005 /Mjöfors et al. 2007/. However, wind is not a parameter included in the LPJ-GUESS model. Accumulation in living tissue is normally the dominant sink for carbon, which was also the case for Forsmark.

Some vegetation types are considered to be more important for long-term accumulation of matter For example, vegetation types periodically inundated by water have a higher accumulation of matter, forming peat, than other terrestrial vegetation types /Borgmark 2005/. These cover a relatively larger area in Forsmark than in Laxemar-Simpevarp (Tables 8-1 and 8-2). Similarly, some catchments are more important than others with regard to accumulation of organic matter, depending on their constitution. Catchments dominated by younger forests have a higher potential for assimilating bioavailable radionuclides today than catchments with a large proportion of clear-cuts, e.g. Gällsboträsk and 10:5. However, the opposite may be true in a long-term perspective, e.g. 100 years.

The estimated accumulation of carbon in Forsmark may be considered large in a long-term perspective, but should be plausible during certain years, due to high sensitivity to temperature /Lindroth et al. 1998/. The variation between years is further reinforced by the example from Laxemar-Simpevarp, which had a large litter production in the modelled year 2005, resulting in nearly twice as high accumulation in the SOC pool. This does not necessarily mean that long-term accumulation increases, since this is compensated by a higher heterotrophic soil respiration the following years. This indicates that the variation in fluxes between years may be considerable. However, in comparison with other studies, the input data for the different vegetation types has to be regarded as plausible and realistic in a short-term perspective (years).

Table 8-15. Human harvest and consumption of game meat, domestic animals and crops according to the "Regional generic case" in Forsmark.

Human harvest and consumption per year (gC y^{-1})		Vambors-fjärden		Sub-area: Fräken-gropen		Sub-area: Stocksjön		Sub-area: Bolundsfjärden		Gällsbo-träsket		Eckarfjärden		Lake 2:2		Kungsträsket		Sub-area: Norra Bassängen		Sub-area: Graven		Puttan	
”Regional generic case”		mean±SD		mean±SD		mean±SD		mean±SD		mean±SD		mean±SD		mean±SD		mean±SD		mean±SD		mean±SD		mean±SD	
Hunting of moose	Harvest[1]	6,271	917	1,849	270	2,762	404	24,811	3,628	28,809	4,212	28,233	4,128	897	131	1,646	241	4,276	625	5,111	747	2,953	432
	Consumption[2]	2,759	403	814	119	1,215	178	10,917	1,596	12,676	1,853	12,423	1,816	395	58	724	106	1,881	275	2,249	329	1,299	190
Hunting of roe deer	Harvest[1]	2,589	714	764	210	1,140	314	10,243	2,824	11,893	3,278	11,656	3,213	370	102	679	187	1,765	487	2,110	582	1,219	336
	Consumption[2]	1,139	314	336	93	502	138	4,507	1,242	5,233	1,443	5,129	1,414	163	45	299	82	777	214	928	256	536	148
Hunting of European hare	Harvest[1]	11	4.8	3.2	1.5	5.4	2.4	41.8	18.7	31.2	14.0	33.7	15.1	1	0	0.8	0.4	11.1	5.0	12.8	5.8	10.1	4.5
	Consumption[2]	4.7	2.1	1.4	0.6	2.4	1.1	18.4	8.2	13.7	6.2	14.8	6.6	0	0	0.4	0.2	4.9	2.2	5.7	2.5	4.4	2.0
Hunting of mountain hare	Harvest[1]	17	20	5.0	6.0	7.3	8.7	68	81	85	102	82	98	2.8	3.3	5.2	6.2	10	12	12	15	6.3	7
	Consumption[2]	7.5	9	2.2	2.6	3.2	3.8	30	36	38	45	36	43	1.2	1.5	2.3	2.7	4.5	5.4	5.5	6.6	2.8	3.3
Domestic animals (cattle + sheep)	Harvest[1]	0		0		3,753		0		15,855		137,508		0		0		0		0		0	
	Consumption[2]	0		0		1,163		0		4,915		42,627		0		0		0		0		0	
Milk	Production and consumption	0		0		22,252		0		94,017		815,387		0		0		0		0		0	
Crop	Production and consumption	0		0		0		0		0		243,961	6,420	0		0		0		0		0	

[1] Live biomass.

[2] Utilized carcass weight.

Table 8-16. Human harvest and consumption of game meat, domestic animals and crop according to the “Regional generic case” in Laxemar-Simpevarp.

Human harvest and consumption per year (gC y^{-1}) ”Regional generic case”		Area 6:1 mean±SD		Area 7:1 mean±SD		Area 7:2 mean±SD		Area 8:1 mean±SD		Area 9:1 mean±SD		Area 9:2 mean±SD		Area 9:3 mean±SD		Area 10:1 mean±SD		Area 10:2 mean±SD		Area 10:3 mean±SD	
Hunting of moose	Harvest[1]	23,117	4,975	2,461	530	20,091	4,324	5,712	1,229	21,292	4,583	8,854	1,906	2,561	551	39,700	8,544	5,309	1,143	3,685	793
	Consumption[2]	10,171	2,189	1,083	233	8,840	1,903	2,513	541	9,369	2,016	3,896	838	1,127	243	17,468	3,760	2,336	503	1,622	349
Hunting of roe deer	Harvest[1]	12,582	5,828	1,339	620	10,935	5,065	3,109	1,440	11,589	5,368	4,819	2,232	1,394	646	21,608	10,008	2,890	1,338	2,006	929
	Consumption[2]	5,536	2,564	589	273	4,811	2,228	1,368	634	5,099	2,362	2,120	982	613	284	9,507	4,404	1,271	589	883	409
Hunting of European hare	Harvest[1]	43	17	1.5	0.6	21	8	3.0	1.2	40	16	14.5	5.7	5.8	2.3	59	23	9.3	3.7	4.0	1.6
	Consumption[2]	19	7.4	0.7	0.3	9	3.6	1.3	0.5	17	6.9	6.4	2.5	2.5	1.0	26	10	4.1	1.6	1.8	0.7
Hunting of Mountain hare	Harvest[1]	59	43	7.2	5.2	56	40	17	12	55	39	23	17	6.3	4.5	106	76	14	9.9	10	7.4
	Consumption[2]	26	19	3.2	2.3	25	18	7.4	5.3	24	17	10	7.4	2.8	2.0	47	34	6.1	4.4	4.5	3.2
Domestic animals	Harvest[1]	556,486		0		228,916		13,737		516,494		174,074		71,848		776,643		108,610		51,696	
	Consumption[2]	201,716		0		82,978		4,979		187,220		63,099		26,044		281,519		39,369		18 739	
Milk	Production and consumption	1.7E+06		0		7.2E+05		4.3E+04		1.6E+06		5.4E+05		2.2E+05		2.4E+06		3.4E+05		1.6E+05	
Crop	Production and consumption	6.5E+06	3.2E+05	0	0	2.9E+06	1.4E+05	0	0	5.4E+06	2.6E+05	3.0E+06	1.5E+05	1.0E+06	5.1E+04	6.1E+06	3.0E+05	1.4E+06	6.8E+04	6.4E+05	3.1E+04

[1] Live biomass.

[2] Utilized carcass weight.

Table 8-16. (Continued from previous page.)

Human harvest and consumption per year (gC y^{-1}) ”Regional generic case”		Area 10:4		Area 10:5		Area 10:6		Area 10:7	
		mean±SD		mean±SD		mean±SD		mean±SD	
Hunting of moose	Harvest[1]	11,552	2,486	3,348	721	10,265	2,209	7,027	1,512
	Consumption[2]	5,083	1,094	1,473	317	4,516	972	3,092	665
Hunting of roe deer	Harvest[1]	6,288	2,912	1,822	844	5,587	2,588	3,825	1,771
	Consumption[2]	2,767	1,281	802	371	2,458	1,139	1,683	779
Hunting of European hare	Harvest[1]	24	9.2	2.4	0.9	7.6	3.0	4.2	1.6
	Consumption[2]	10	4.1	1.1	0.4	3.4	1.3	1.8	0.7
Hunting of Mountain hare	Harvest[1]	29	21	10	6.9	30	21	21	15
	Consumption[2]	13	9.2	4.3	3.1	13	9.4	9.0	6.5
Domestic animals	Harvest[1]	297,902		31,456		102,688		55 806	
	Consumption[2]	107,984		11,402		37,222		20,229	
Milk	Production and consumption	9.3E+05		9.8E+04		3.2E+05		1.7E+05	
Crop	Production and consumption	4.0E+06	1.9E+05	3.5E+05	1.7E+04	8.6E+05	4.2E+04	4.8E+05	2.4E+04

[1] Live biomass.

[2] Utilized carcass weight.

Table 8-17. Human harvest and consumption of domestic animals and crop according to the “Potential self-sustainable case” and “case 100% crop” in Forsmark. Consumption via hunting is the same as in the regional case in Table 8-17.

Harvest and human consumption per year (gC y^{-1})		Vambors-fjärden	Sub-area: Fräken-gropen	Sub-area: Stocksjön	Sub-area: Bolunds-fjärden	Gällsbo-träsket	Eckar-fjärden	Lake 2:2	Kungs-träsket	Sub-area: Norra Bassängen	Sub-area: Graven	Puttan
”Self sustainable case”												
Domestic animals	Harvest	5,7E+04	1,7E+04	2,9E+04	2,2E+05	1,7E+05	1,8E+05	3,4E+03	4,3E+03	5,9E+04	6,8E+04	5,4E+04
(Cattle)	Consumption	1,8E+04	5,4E+03	9,1E+03	7,0E+04	5,2E+04	5,6E+04	1,1E+03	1,3E+03	1,8E+04	2,1E+04	1,7E+04
Milk	Production and consumption	6,2E+05	1,9E+05	3,2E+05	2,4E+06	1,8E+06	2,0E+06	3,8E+04	4,6E+04	6,4E+05	7,5E+05	5,9E+05
Crop	Production and consumption	2,5E+06	7,7E+05	1,3E+06	9,9E+06	7,4E+06	8,0E+06	1,5E+05	1,9E+05	2,6E+06	3,0E+06	2,4E+06
”Case 100% crop”												
Crop	Production and consumption	9,7E+06	2,9E+06	4,9E+06	3,8E+07	2,8E+07	3,1E+07	5,9E+05	7,2E+05	1,0E+07	1,2E+07	9,1E+06

Table 8-18. Human harvest and consumption of domestic animals and crop according the “Potential self-sustainable case” and “case 100% crop” in Laxemar-Simpevarp. Consumption via hunting is the same as in the regional case in Table 8-18.

Harvest and human consumption per year (gC y^{-1})		Area 6:1 mean	Area 7:1 mean	Area 7:2 mean	Area 8:1 mean	Area 9:1 mean	Area 9:2 mean	Area 9:3 mean	Area 10:1 mean	Area 10:2 mean	Area 10:3 mean	Area 10:4 mean	Area 10:5 mean	Area 10:6 mean	Area 10:7 mean
”Self-sustainable case”															
Domestic animal	Harvest[1]	2,3E+05	8,0E+03	1,1E+05	1,6E+04	2,1E+05	7,6E+04	3,0E+04	3,1E+05	4,9E+04	2,1E+04	1,2E+05	1,3E+04	4,0E+04	2,2E+04
(cattle)	Consumption[2]	7,1E+04	2,5E+03	3,4E+04	4,9E+03	6,6E+04	2,4E+04	9,5E+03	9,8E+04	1,5E+04	6,7E+03	3,9E+04	4,0E+03	1,3E+04	6,9E+03
Mil^{k}	Production and consumption	2,5E+06	8,7E+04	1,2E+06	1,7E+05	2,3E+06	8,3E+05	3,3E+05	3,4E+06	5,4E+05	2,3E+05	1,4E+06	1,4E+05	4,4E+05	2,4E+05
Crop	Production and consumption	1,1E+07	4,0E+05	5,4E+06	7,9E+05	1,0E+07	3,8E+06	1,5E+06	1,6E+07	2,5E+06	1,1E+06	6,2E+06	6,4E+05	2,0E+06	1,1E+06
”Case 100% crop”															
Crop	Production and consumption	4,4E+07	1,5E+06	2,1E+07	3,0E+06	4,0E+07	1,5E+07	5,8E+06	6,0E+07	9,5E+06	4,1E+06	2,4E+07	2,5E+06	7,7E+06	4,2E+06

[1] Live biomass.

[2] Utilized carcass weight.

Table 8-19 Fungi and berry potential maximum yield for each of the 11 modelled catchments in Forsmark.

Catchment	Fungi yield (gC y^{-1})	Berry yield (gC y^{-1})
Bolundsfjärden	1.84E+05	7.96E+04
Eckarfjärden	2.33E+05	9.93E+04
Fräkengropen	1.36E+04	5.62E+03
Gällsboträsk	2.32E+05	9.78E+04
Graven	3.37E+04	1.51E+04
Kungsträsket	1.41E+04	6.02E+03
Lake 2:2	7.48E+03	3.33E+03
Norra Bassängen	2.79E+04	1.24E+04
Puttan	1.69E+04	7.78E+03
Stocksjön	2.01E+04	8.51E+03
Varmbörsfjärden	4.62E+04	2.02E+04

Table 8-20 Fungi and berry potential maximum yield for each of the 14 modelled catchments in Laxemar-Simpevarp.

Catchment	Fungi yield (gC y^{-1})	Berry yield (gC y^{-1})
6:1	2.15E+05	6.02E+04
7:1	2.46E+04	5.39E+03
7:2	1.97E+05	5.39E+03
8:1	5.84E+04	1.68E+04
9:1	2.00E+05	5.74E+04
9:2	8.00E+04	1.80E+04
9:3	2.24E+04	6.07E+03
10:1	3.90E+05	1.16E+05
10:2	4.91E+04	1.38E+04
10:3	3.61E+04	9.66E+03
10:4	1.04E+05	2.88E+04
10:5	3.38E+04	8.66E+03
10:6	1.05E+05	2.72E+04
10:7	7.21E+04	1.82E+04

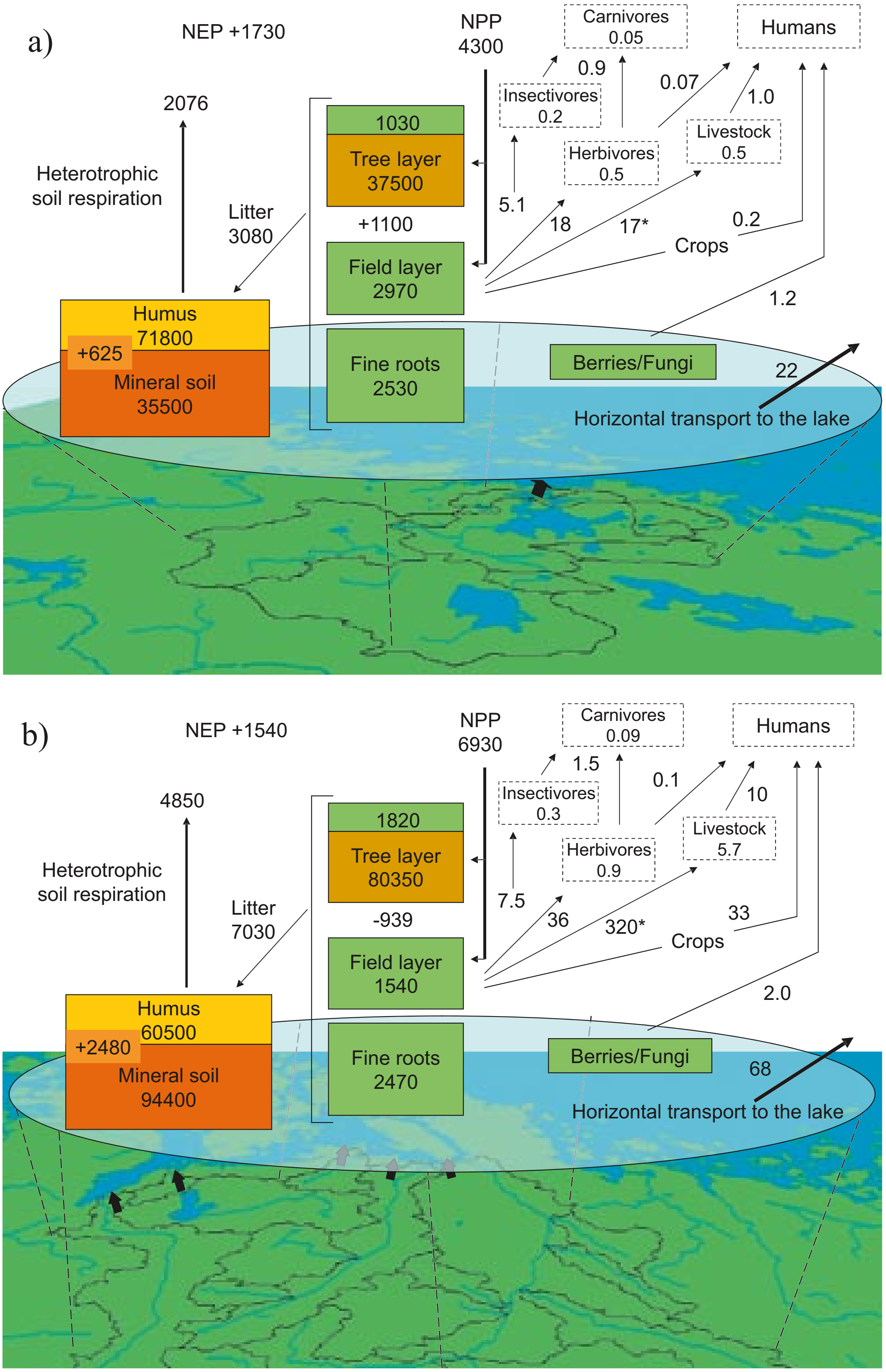


Figure 8-4. *Descriptive model of the total carbon balance in all the investigated catchment areas in a) Forsmark and b) Laxemar-Simpevarp, where modelled pools and fluxes for all vegetation types have been added together. Production of berries/fungi is the potential harvest available to biota. The black arrows on the map indicate discharge into the Baltic Sea. All pools (boxes) are in 1x10*^{6} *gC and fluxes (arrows) are in 1x10*^{6} *gC y*$^{-1}$*. Changes in the soil organic carbon pool and the vegetation pool are indicated by a +/– before the figure. *Livestock consumption includes both locally produced and imported fodder. Animal consumption has not been subtracted from the net ecosystem production (NEP).*

8.5.2 Food web

The flux of carbon from autotrophic production to herbivores is close to 1% of the NPP in Forsmark but almost 5% in Laxemar-Simpevarp. This difference is due to the higher abundance of livestock in Laxemar-Simpevarp, and if that is excluded, consumption is close to 0.5% at both sites. However, a portion of the NPP is confined to wood, a poor quality food largely unavailable to most herbivores. Herbivore consumption efficiency is normally 1–40% of NPP and is usually low in woods but reaches higher values in grasslands /Chapin et al. 2002/. The most important herbivore with regard to consumption and production (except for livestock) in Forsmark is roe deer, closely followed by moose, while the opposite is true in Laxemar-Simpevarp. Livestock consumption is the largest flux of carbon from the vegetation, but there is a greater difference between livestock and wild game consumption in Laxemar-Simpevarp than in Forsmark, due to higher abundances of livestock in Laxemar-Simpevarp. In some catchments where livestock was absent the consumption of vegetation decreased drastically.

Insect herbivores were not considered in the calculations, but studies of herbivory by insects on Scots pine estimated it to be 0.7% of the total needle biomass and 2.5% of the total needle production in one year /Larsson and Tenow 1980/. Root consumption by phytophagous nematodes was estimated to 0.3% of the annual production of fine roots /Magnusson and Sohlenius 1980/. Herbivory by insects during outbreaks may, however, amount to a major portion (up to 50%) of NPP /Schowalter et al. 1986/. If the figures for Scots pine are representative for the landscape as a whole they indicate that this consumption would be of similar size as for the vertebrate herbivores.

8.5.3 Human consumption

The potential flux of carbon to humans from products derived from vegetation was of the same order as herbivore consumption when the catchment area contained agriculture land. The potential human consumption of meat and milk was one order of magnitude lower than the consumption of plants and was similarly dependent on the catchment's potential to sustain cattle. The highest fluxes of carbon to humans are found within catchments that both cultivate crops and have enough arable land to sustain cattle. These calculations are based on the assumption that livestock only eat fodder grown within the catchment, thereby maximizing the potential exposure to accumulated bioavailable radionuclides within a catchment. If the land was used to produce maximum yield, i.e. by growing barley on all arable land, this would increase the flux of carbon from vegetation to humans by 30%, but would on the other hand eliminate the lower carbon flux from cattle to humans. The flux of carbon from hunting is low in comparison with the two other fluxes. These figures suggest that the largest potential fluxes of radionuclides via food intake to humans are found within catchments having agricultural activities and that arable land is the single most important vegetation type for potential exposure of cattle and humans to radionuclides. The absolute figures can be used to calculate human exposure, depending on population size and habits with regard to use of locally produced food and import and export of food.

The three case studies of human production of food (crops, meat and milk) showed that current production is far from potential production with regard to organic matter. In Forsmark, food production based on regional statistics was only 0.8% of the potential maximum production, assuming crop production on all agricultural land. The corresponding figure for Laxemar-Simpevarp was 15%, suggesting a higher utilization of potential resources in that area.

The potential berry and fungi yield in Forsmark is higher than the actual food production from hunting, crops or cattle. This is not the case in Laxemar-Simpevarp, where both milk and crop production are higher. However, the high berry and fungi yield is the potential yield that is available for picking, and the actual utilization of berries in Sweden has been estimated to be close to 5–7% of the yield /Kardell and Carlsson 1982/.

8.5.4 Confidence and uncertainties

There is great spatial variation within a regional area as an effect of different abiotic and biotic conditions and of disturbances, such as logging and thinning in forestry management or agriculture. In this section, results have been presented in order to describe the present-day situation with regard to vegetation types, their spatial distribution, the food web and the human land use. Furthermore, two contrasting potential cases of human use of the landscape were presented.

In a previous modelling approach for the Laxemar-Simpevarp area /Löfgren et al. 2006/ using both field-derived data and literature to describe the vegetation and soil pools and fluxes, the NPP range between the different catchments was between 432 and 709 gC m^{-2} y^{-1} (including EM mycelia production). The corresponding figures using the LPJ-GUESS-modelled carbon balances resulted in the range 425 to 534 gC m^{-2} y^{-1} (no EM mycelia production). EM mycelia contributed less than 80 gC m^{-2} y^{-1} per catchment, suggesting that this estimate was lower and had less variation in space than the previous estimate. The approach presented here is built on vegetation data generated by a model driven by site-specific climate parameters, where the different vegetation types have been modelled during a specific time period to approximate an appropriate age of the different vegetation types describing the vegetation at the site (see Section 7.2.2). Using a specific year to describe current conditions (in 2005) reduces the variation in climate-driven fluxes in comparison with an approach based on data from estimates describing different years (and consequently different solar radiations, soil temperatures etc.). Moreover, the modelled fluxes are mechanistically correlated, whereas they were not directly related to each other in the previous model version for Laxemar-Simpevarp (apart from being representative for a certain vegetation type). However, it is important to note that the results in the previous version are plausible, whereas the results presented here are considered to be more representative in a short-term (10-year) perspective. These short-term predictions may be compared with the long-term (100-year) modelling in Chapter 7, predicting long-term assimilation and accumulation in ecosystems at both sites.

The use of three different scenarios to describe human use of the landscape is one way of describing the potential variation in these properties. It is use that is the major factor determining the potential harvest rather than a comparatively small variation in the production of different crops or in the production estimates for different animals. The potential agriculture land in a catchment would therefore set the upper limit to the potential food production in an area. The potential for locally produced food is nearly 120 and 7 times higher, respectively (Forsmark and Laxemar-Simpevarp) compared with current production in the regions.

9 Distribution of elements among ecosystem compartments and mass balances

9.1 Introduction

A large number of radionuclides are of interest when considering a potential release from a deep repository into the biosphere. In most cases it is not possible to study the actual long-lived radionuclides themselves, so the distribution patterns of naturally occurring radionuclides or their stable isotopes have been used to study the long-term behaviour of the radionuclides that may originate from nuclear waste e.g. /Vera Tome et al. 2003, Chen et al. 2005/. Moreover, by describing the distribution of elements in general, and estimating the large inputs and outputs in the ecosystem, it is possible to infer and contrast different patterns caused by elements with different properties. Such an exercise would also describe the range in behaviour of different elements, which could be indicative of the uncertainties involved in predicting the behaviour of elements in ecosystems. The biogeochemical cycling and storage of elements in an ecosystem is dependent on a large number of variables, such as climate, geological heterogeneity, flux of water and vegetation e.g. /Likens and Borman 1995/. Moreover, the interaction between elements and non-living and living compartments in an ecosystem are important in defining and regulating their flux and storage in an ecosystem e.g. /Chapin et al. 2002/.

This chapter describes how mass balance calculation of phosphorus and three naturally occurring radionuclides/stable isotopes were used to describe input and outputs, and to estimate accumulation within catchment areas. Furthermore, the distribution for over 60 different elements among ecosystem compartments was described within the previously described 11 terrestrial catchments in Forsmark and 14 catchments in Simpevarp. Carbon, which has been described in Chapter 9, represents organic material and is equivalent to energy transfer within the food webs. Phosphorus is a macronutrient and can be regarded as an potential analogue to highly bioavailable radionuclides, and thorium, uranium and iodine are naturally occurring radionuclides/elements with isotopes (^{232}Th and $^{229\mathrm{Th}}$, ^{2XX}U and ^{129}I) that have been suggested as being of importance in case of a release from a deep-sited high-level radionuclide repository. Uranium and thorium have no known biological role, whereas iodine appears to be a trace element essential to biota. These two naturally occurring radionuclides and iodine were chosen to cover a broad span with regard to radionuclide behaviour in the soil, since they have different soil solid/liquid partition coefficients (Kd), ^{232}Th and ^{229}Th (3,200–89,000 l·kg^{-1}, /Thibault et al. 1990/), ^{2XX}U (15–1,600 l·kg^{-1}, /Thibault et al. 1990/) and ^{129}I (8–80 l·kg^{-1}, /Sheppard et al. 2006/). A low Kd means a higher solubility in the soil water and is therefore potentially more bioavailable.

A large data set is presented in this chapter for the purpose of supporting further calculations and discussions in the safety analysis for the two sites. Much of the data will therefore only be presented in tables and not be further discussed in this chapter.

9.2 Methods

9.2.1 Conceptual model

Mass balance models describing the inputs and outputs of a large number of elements at the catchment scale were constructed in accordance with the conceptual illustration in Figure 9-1. The estimated input was atmospheric deposition, and the output was horizontal transport by water. The element content was estimated for four pools within each catchment. The consumer pool consists of carnivores, insectivores and herbivores, whereas the producer pool consists of all the vegetation above- and below-ground. The soil was divided into a litter/ humus pool and a mineral soil pool, based on differences in organic carbon content and adsorption properties. In the case of phosphorus, which is a well-described element, certain internal fluxes, such as weathering and vegetation demand, were also included to further elaborate the resulting mass balances.

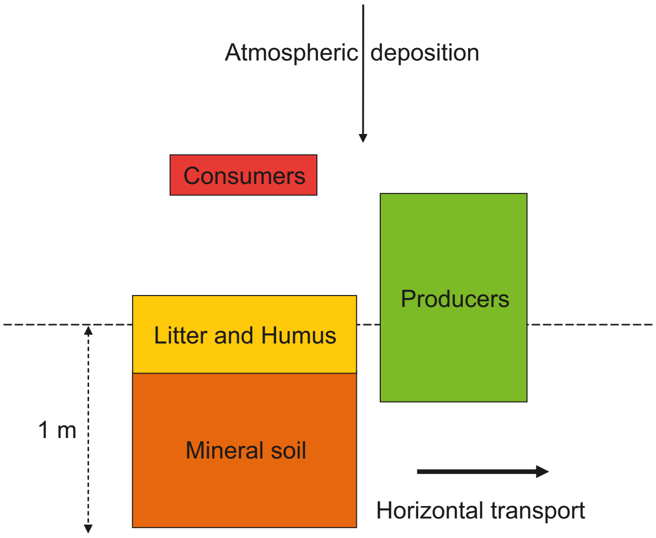


Figure 9-1. *The pools and fluxes that were used to describe the distribution of the four elements Th, U, I and P in the terrestrial catchments.*

9.2.2 Estimation of element content

Elements can be divided according to physical and chemical characters into metalloids, metals, non-metals, lanthanides and actinides. The 62 elements considered in this chapter are metals: Ag, Al, Ba, Be, Ca, Cd, Cs, Co, Cr, Cu, Fe, Ga, Hf, Hg, K, Li, Mg, Mn, Mo, Na, Nb, Ni, Pb, Rb, Sc, Sn, Sr, Ta Ti, Tl, V, W, Y, Zn, Zr; non-metals: Br, C, Cl, I, N, P, S, Metalloids: As, B, Sb, Si; Lanthanides: Ce, Dy, Er, Eu, Gd, Ho, La, Lu, Nd, Pr, Sm, Tb, Tm, Yb; and actinides Th, U. The chemical sampling of the different ecosystems and the fauna is described for Forsmark in /Hannu and Karlsson 2006/ and for Simpevarp in /Engdahl et al. 2006/.

Ten of the elements analyzed in soil samples were reported as their oxides (Al_2O_3, CaO, Fe_2O_3, K_2O, MgO, MnO, Na_2O, P_2O_5, SiO_2, TiO_2). These values were converted to the concentration of each element using molar masses.

Some of the measurement results were below the detection limit, and these were replaced with a value equal to half the detection limit. For some of the elements, a large portion of the measurements were below the detection limit for consumers, and for the following elements these constituted a majority of the measurements: Ag, As, Be, Ga, Li, Ni, Pb, Sb, Th, Tl, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, V, W, I. Half the detection limit was nonetheless used for these values.

The carbon content in different compartments was modelled with LPJ-GUESS (Chapter 7) and estimated from site-specific measurements (wetlands) for a number of vegetation types covering the landscape. The carbon content of different compartments was added together in accordance with the pools in Figure 10-1. The element content of the pools in Figure 10-1 was estimated using the ratio between the element and carbon concentrations from the chemical characterization of a number of localities representing different vegetation types (Tables 9-1 and 9-2). This ratio was then multiplied by the carbon content of each compartment to give the element content of each compartment. The catchment areas are in the range of 0.07 to 2.08 km^2 and are further described in Figures 8-2 and 8-3, and Tables 8-1 and 8-2.

Vegetation and soil

In total, six different ecosystems were used to describe the catchments at each site with regard to differences in the ratio between each element and carbon. These descriptions of ratios were from a number of localities sampled at each site (Tables 9-1 and 9-2). The description of carbon pools presented in Chapter 8 used 15 different ecosystems to characterize the spatial differences with regard to carbon pools. Of these, the carbon pools for 12 ecosystems were modelled using the dynamic model LPJ-GUESS (see Chapter 7), whereas the carbon pools for the three wetland types were estimated using field-estimated site data (see Chapter 8).

These 15 ecosystems was grouped according to similarities in tree species or history, e.g. clear-cut and forest, into the five different ecosystems that were used to characterize the spatial differences with regard to other elements than carbon (Tables 9-3 and 9-4). The carbon content of each compartment according to Figure 9-1 was summed across the different ecosystems (Tables 9-3 and 9-4) and then multiplied by the vegetation-type-specific ratio between the element and carbon.

Data describing phosphorus concentrations in the wood for the Laxemar-Simpevarp localities were all 5 to 15 times higher than the Forsmark values (48 to 53 mg P g^{-1} dw). These values were replaced with a value from a locality in the southern Sweden (Skogaby) from a young Norway spruce forest that was somewhat more than twice as high the Forsmark value (120 mg P g^{-1} dw) /Scarascia-Mugnozza et al. 2000/. See also discussion under 10.3.2 concerning other elements in the wood sample. The detection limit for iodine was three times higher for the wood samples from Laxemar-Simpevarp, and the decision to use half the detection limit for their concentration therefore caused a non-existing pattern. It was therefore assumed that the iodine content of the wood was similar and the same value was used (half the detection limit was 0.05 mg g^{-1} dw).

Table 9-1. Vegetation types describing the landscape and origin of element concentration data that described these vegetation types in Forsmark. Most of the data were from Forsmark, but some came from Laxemar-Simpevarp. Most localities in column two were only sampled once for each pool. The SKB ID code is given in parentheses.

Vegetation type	Origin of chemistry data
Deciduous / Mixed forest	Mixed Norway spruce forest (AFM001068, Forsmark).
Coniferous forest	Norway spruce forest (AFM001247, Forsmark)
Forested wetland	Alder-Norway spruce, Alder wetland, and Norway spruce on partially drained peatland (AFM001076 Forsmark; ASM001434, ASM001440 Simpevarp).
Wetland	Alder wetland (field and bottom layer, and fine roots, AFM001076, Forsmark), mire (peat, Rönningerna, PFM006024, Forsmark)
Open wetland to lake	Reed belt (Frisksjön, ASM000110, ASM000111, ASM000112, Simpevarp) and humus (reed peat, PFM006024, Forsmark).
Agriculture land / Pasture	Mixed Norway spruce forest (soil, field layer, AFM001068, Forsmark)

Table 9-2. Vegetation types describing the landscape and origin of element concentration data that described these vegetation types in Laxemar-Simpevarp. Most of the data were from Laxemar-Simpevarp, but some came from Forsmark. Most localities in column two were only sampled once for each pool. The SKB ID code is given in parentheses.

Vegetation type	Origin of chemistry data
Deciduous / Mixed forest	Oak forest (ASM001426, Simpevarp).
Coniferous forest	Norway spruce forest (ASM001440, Simpevarp).
Forested wetland	Alder-Norway spruce, Alder wetland, and Norway spruce on partially drained peatland (AFM001076 Forsmark; ASM001434, ASM001440 Simpevarp).
Wetland	Norway spruce on partially drained peatland (field and bottom layer, and roots) (ASM001440, Simpevarp, 1), peat (Klarebäcksmossen, PSM006562, Simpevarp).
Open wetland to lake	Reed belt (Frisksjön, ASM000110, ASM000111, ASM000112, Simpevarp) and humus (reed peat, PFM006024, Forsmark).
Agriculture land / Pasture	Oak forest (ASM001426, Simpevarp).

Table 9-3. Subset of vegetation types that were chemically characterized in left column and vegetation types that were included in these in right column for Forsmark.

Vegetation type	Carbon-modelled vegetation types (in accordance with the vegetation map categories)
Deciduous/Mixed forest	Old deciduous-dominated forest Mixed forest (conifers/deciduous)
Coniferous forest	Young Scots pine Old Scots pine forest, mesic-wet types Dry Sots pine forest on acid rocks Old Norway spruce forest, mesic-wet types Old clear-cut, birch thicket Young Norway spruce Clear-cut
Forested wetland	Forested wetland, conifer-dominated Forested wetland, deciduous-dominated
Wetland	Open wetland
Open wetland to lake	Open wetland to lake
Agriculture land/Pasture	Arable land Pasture

Table 9-4. Subset of vegetation types that were chemically characterized in left column and vegetation types that were included in these in right column for Laxemar-Simpevarp.

Vegetation type	Carbon-modelled vegetation types (in accordance with the vegetation map categories)
Deciduous / Mixed forest	Oak-dominated deciduous forest Mixed forest (conifers/deciduous)
Coniferous forest	Young spruce-dominated forest, mesic-wet types Old spruce-dominated forest, mesic-wet types Young pine-dominated forest, mesic-wet types Old pine-dominated forest, mesic-wet types Dry pine forest on acid rocks New clear-cut 1999–2006 Old clear-cut, birch thicket
Forested wetland	Forested wetland, pine-dominated Forested wetland, birch-dominated
Wetland	Open wetland
Open wetland to lake	Open wetland to lake
Agriculture land / Pasture	Arable land Pasture

Consumers

The chemical characterization of the consumers was put together according to the three functional groups Herbivore I, Herbivore II and Carnivores at both sites. Herbivore I represented rodents and birds with a high metabolism compared with the larger species included in Herbivore II (Table 9-5).

9.2.3 Input and output of elements to ecosystems

The input of elements in this area is from atmospheric deposition, whereas the output is horizontal transport by water into streams lakes and the sea. No attempt has been made to describe the weathering except for the phosphorus mass balance.

The element transport in surface water was estimated from concomitant measurements of concentrations and discharge in streams of Forsmark /Tröjbom et al. 2007, Appendix F/ and Laxemar-Simpevarp /Tröjbom et al. 2008, Appendix C/.

Table 9-5. Consumers are divided into three functional groups for which the element content is estimated from a subset of sampled representatives (column two). For example, elemental analysis of Fox represents the functional group carnivores.

Site	Functional group	Species/group	Sample size
Forsmark	Carnivores	Fox	1
	Herbivore I	Moose	7
	Herbivore II	Rodents*	8
Simpevarp	Carnivores	Fox	3
	Herbivore I	Moose	3
		Roe deer	3
	Herbivore II	Rodents*	9

*Estimates for rodents covered several species and a number of aggregated samples /Hannu and Karlsson 2006, Engdahl et al. 2006/.

Table 9-6. Subset of functional consumer groups that were chemically characterized in left column and different taxa included in these in right column for both sites.

Functional group	Species/group included
Carnivore	Fox, birds, insectivores (birds, amphibians, reptiles)
Herbivore I	Moose, roe deer, hares, wild boar, livestock
Herbivore II	Rodents, birds

Atmospheric deposition

The sources for estimating atmospheric deposition are presented in Table 9-8 (additional elements in Appendix 6). The deposition was multiplied by the precipitation for phosphorus and iodine, where the deposition was estimated as wet deposition in precipitation. For uranium and thorium, data from southern Sweden were used, where the total atmospheric load was estimated in beech forest for the winter period /Tyler and Olsson, 2006/. They suggested further that this load was greater during the winter period than during the summer period. Consequently, the winter deposition (in Tables 9-7 and 9-8) was multiplied by 1.5 to approximate the total atmospheric deposition. This might entail an underestimate, but the dry deposition is higher in forests and the forests represented only 61% and 74% of the land area in the modelled catchments of Forsmark and Laxemar-Simpevarp, respectively.

Table 9-7 Values of atmospheric deposition (dry deposition and/or precipitation) used in mass balance models of Forsmark lakes. Data from 1) /Tröjbom and Söderbäck 2006a/, 2) /IVL 2003/, 3) /Tyler and Olsson 2006/.

Element	Precipitation (mm year^{-1})	Deposition (g m^{-2} year^{-1})	Reference	Comment
P	559	0.012	1	In precipitation as a mean from two stations (PFM002457 and PFM002564)
U	559	0.000002	3	Estimate of atmospheric deposition during the winter period in a deciduous forest in southern Sweden
Th	559	0.000005	3	Estimate of atmospheric deposition during the winter period in a deciduous forest in southern Sweden
I	559	0.00028	1	In precipitation based on two measurements at the site that were both below the detection limit of 1µg/l. Half the detection limit was assumed as the deposition value, which was in the lower range of the iodine deposition interval reported by /Sheppard et al. 2002/.

Table 9-8. Values of atmospheric deposition (dry deposition and/or precipitation) used in mass balance models of Frisksjön in Laxemar-Simpevarp. Data from 1) /IVL 2008/, 2) /Knape 2001/, 3)/Tyler and Olsson 2006/, 4) /Tröjbom and Söderbäck 2006b/.

Element	Precipitation (mm $year^{-1}$)	Deposition (g m^{-2} $year^{-1}$)	Reference	Comment
P	600	0.027	2	Data from Äspö, Laxemar-Simpevarp
U	600	0.000002	3	Estimate of atmospheric deposition during the winter period in a deciduous forest in southern Sweden
Th	600	0.000005	3	Estimate of atmospheric deposition during the winter period in a deciduous forest in southern Sweden
I	600	0.0003	4	In precipitation based on two measurements in Forsmark that both were below the detection limit of 1µg/l. Half the detection limit was assumed as the deposition value, which was in the lower range of the interval reported by /Sheppard et al. 2002/. Corrected for precipitation amount in Laxemar-Simpevarp

Horizontal transport with water

The transport of elements in surface water has been estimated from concomitant measurements of concentrations and discharge in streams in Forsmark and Laxemar-Simpevarp /Tröjbom et al. 2007, Appendix F, Tröjbom et al. 2008, Appendix C/. Such data were available for a number of elements (e.g. phosphorus). For the other elements, correlations between the concentrations of the more and less abundant elements were used /Tröjbom et al. 2007, Tröjbom et al. 2008/.

Weathering of phosphorus

Weathering of phosphorus was calculated for both sites. /Olsson and Melkerud 1989/ studied chemical and mineralogical changes during the genesis of a Podsol in southern Sweden. They determined the average rate of weathering for phosphorus since the last deglaciation (material < 2 mm) to 0.009 gm^{-2}. This rate may have changed over time due to e.g. climatic variations and different vegetation. /Ulén and Snäll 1998/ compared the weathering rates in a forest catchment with the rates from an arable field (grain sizes < 2 mm). The rate of base cation weathering was estimated to be 10 times higher in the arable soil compared with the forest area. Soils used as arable land are generally more fine-grained than forest soils. Fine-grained material is more easily affected by weathering and the high weathering rates in the area used as arable field can therefore be explained by a higher content of fine material in that area. Accordingly, all vegetation types with more coarse-grained soil types were assigned the average weathering value from above, while the more fine-grained soil types – such as mixed conifer/deciduous forest deciduous forest, pastures and arable land – were the assigned the higher rate. Both sites are young and the expected weathering is expected to be somewhat higher than the long-term mean /Hedenström and Sohlenius 2008, Sohlenius and Hedenström 2008/, but this was not accounted for in the calculations.

9.3 Results and discussion

9.3.1 Distribution of elements among pools for all catchments

In general, most elements have their main distribution in the soil compartments except for chlorine, where nearly 75–80% of the total terrestrial chlorine pool is found in the vegetation. The non-metals are all found to a large extent in the producers, where the halogens are highly reactive and water-soluble. Moreover, N, P, S and Cl are all essential nutrients for the plant. This also explains why many other elements occur in the producer pool, where B, Ca, Cu, K, Mg, Mn, Mo, Ni, Zn and I are regarded as micronutrients. Perhaps more interesting is the fact that Sb, Be, Cd, Hg, Rb, Sr, Tl and Br occurred to a certain extent in the plants. Sb is usually regarded as having a relative high mobility in the environment due to its occurrence in water, in association with carbon and bound to iron hydroxides /Greger 2004/. As a soluble salt, Be is easily taken up by plants and seems to follow the same route as Mg and Ca. Cd, a toxic heavy metal, and Hg are both readily absorbed by plant roots, and it was also here the highest concentrations were found. Interestingly, similar high concentrations were found for Hg in the bottom layer, suggesting that atmospheric deposition is an important flux for Hg. Rb follows the uptake route of K, and the distribution factor Rb/K is close to one, even though there is a slight discrimination factor against Rb compared with K. Sr is often associated with Ca and the root uptake is related to mass-flow and exchange diffusion. Sr is mainly accumulated in the roots. Br has a strong correlation with organic carbon and is able to substitute for Cl in plants. Tl has chemical behaviour that is analogous to K /Greger 2004/.

A number of elements are to a greater extent represented in the pool of producers in Laxemar-Simpevarp, such as B, Ag, Ba, Ca, Co, Cs, K, Mg, Mn, Pb, Sr, Zn, Br and P. Of these, at least B, Ca, Co, K, Mg, Mn, Zn and P are regarded as essential elements for the plants and Cs, Sr and Br are closely associated with the transport pathways of some nutrients. A closer examination of the data reveals that the concentrations of these elements in the wood sample representing conifer forests were between 3 to 10 times higher than those found in Forsmark. This might suggest that the samples have a large content of phloem tissue and are therefore not representative for describing the biomass of sapwood/heartwood (see also under “Vegetation and soil” above).

The lanthanides differ somewhat in their distribution between the sites. In Laxemar-Simpevarp they are represented to a greater extent in the producers relative to the other compartments than in Forsmark. This is explained by a higher concentration of the elements in bryophytes and in the fine roots (between 2 to 10 times) in the conifer forest samples. This is not reflected to same extent in the humus layer. In any case, this pattern suggests that atmospheric deposition may be higher in the forests of Simpevarp-Laxemar than in Forsmark for this group of elements.

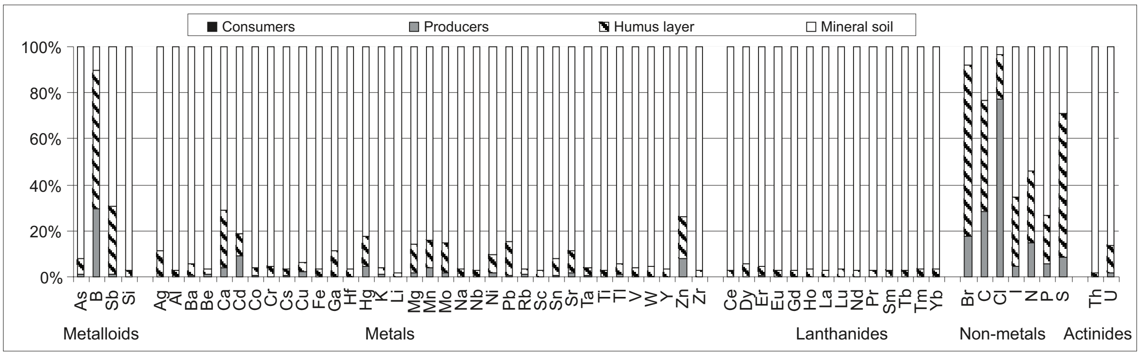


Figure 9-2. Distribution of 62 elements among the four pools mineral soil, humus layer, producers and consumers. Each pool is the sum of all the 11 catchments studied in Forsmark.

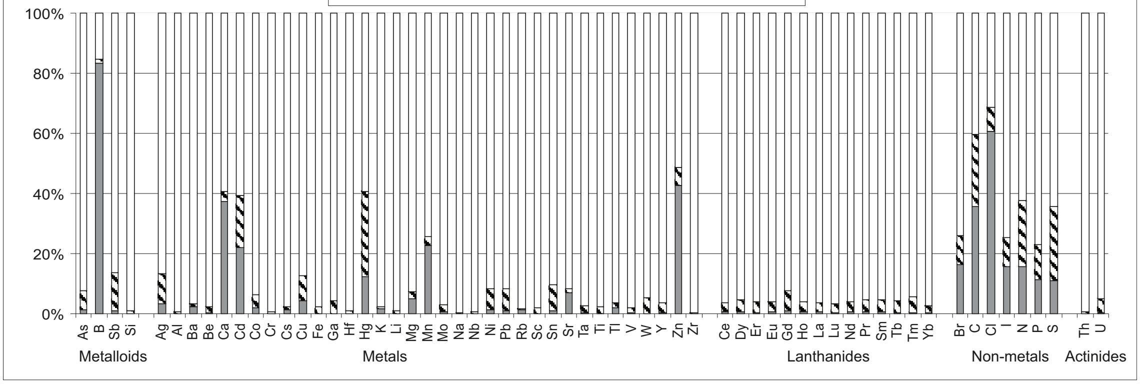


Figure 9-3. Distribution of 62 elements among the four pools mineral soil, humus layer, producers and consumers. Each pool is the sum of all the 14 catchments studied in Laxemar-Simpevarp.

9.3.2 Concentrations of P, Th, U and I among pools within ecosystems

A detailed description of the underlying element concentrations is presented in Figure 9-4 for those elements that were analyzed by the mass balance approach.

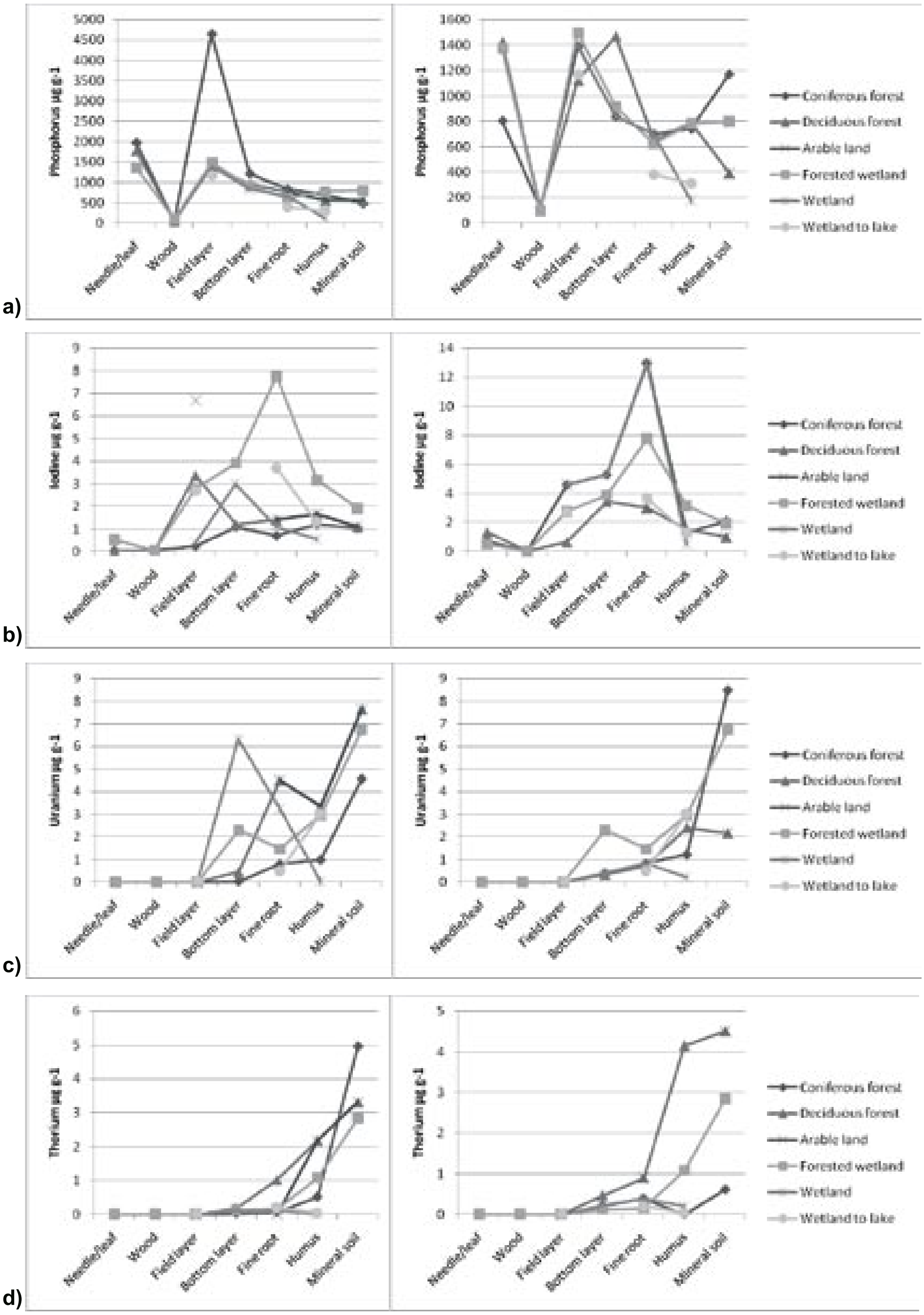


__Figure 9-4.__ The element concentrations for a) phosphorus, b) iodine, c) uranium and d) thorium that were used to describe the pools in six different ecosystems in Forsmark (left) and Laxemar-Simpevarp (right).

9.3.3 Mass balances of P, Th, U and I among catchments

Mass balances for phosphorus, iodine, thorium and uranium for both sites are presented in Table 10-9. More detailed descriptions covering the different catchment areas are presented in Tables 10-10 to 10-17. The calculations suggest a net accumulation of phosphorus within both sites, where most of the atmospheric deposition is accumulated. Export per unit area was less in Forsmark than in Laxemar-Simpevarp: 1.7 mg P m^{-2} y^{-1} and 8.8 mg P m^{-2} y^{-}, respectively. Since NPP is of a similar magnitude for both sites (see Chapter 8), this indicates that the Forsmark soil retains more of the phosphorus and/or that the Laxemar-Simpevarp soil has a higher loss of phosphorus. In fact, the Forsmark soil is rich in calcium carbonate, which precipitates phosphorus to a greater extent, and arable land is more abundant in the Laxemar-Simpevarp catchments (8.5%) than in the Forsmark catchment (0.1%). The largest pool was found in the mineral soil, but a large part of this pool is inaccessible to the biota. Generally, between 20% and 30% of the phosphorus in the soil is available to plants, where the lower figure represents soils with higher pH (> 6.5), which is more applicable to the Forsmark conditions /Chapin et al. 2002/. There is a difference between the sites with regard to the relative phosphorus content of the vegetation and humus pools.

By using the information from the ecosystem model describing carbon pools and fluxes at the regional level for the same area, it is estimated that approximately 310 kg P y^{-1} was used for NPP by the vegetation in Forsmark. It was assumed that phosphorus was required in a proportion corresponding to its concentration in wood and that approximately 31% of the phosphorus was recycled within the vegetation /Finér 1989/. Moreover, by adding accumulation in wetlands, where /Sternbeck et al. 2006/ estimated the long term accumulation of phosphorus in one wetland to be 0.02 g P m^{-2} y^{-1} in Laxemar-Simpevarp, which would suggest that further 25 kg would be accumulated in wetlands (all wetlands included). This would entail that approximately 335 kg P could be accumulated in the area compared with the 83 kg P in Table 10-7. Accumulation is undoubtedly overestimated in the wetlands because many of the wetlands close to the coast in the Forsmark regional area are not yet accumulating peat to any great extent. Another source of phosphorus is weathering, which would make an additional 118 kg available, suggesting a source of 134 kg P so far unaccounted for. Furthermore, atmospheric deposition only included wet deposition, which suggests that the input of phosphorus could be somewhat higher.

A similar calculation for the Laxemar-Simpevarp area suggested that the wetlands accumulated approximately 3 kg P y^{-1} and the NPP used 1,550 kg P y^{-1}. The higher demand is explained by the higher concentration of phosphorus in the wood, see also under "Vegetation and soil". The net accumulation in the mass balance (Table 10-7) and weathering (457 kg P y^{-1}) amounted to 717 kg P, leaving a source of 836 kg P unaccounted for. The unaccounted-for source is decomposition of litter, where phosphorus is released.

Iodine shows a somewhat similar pattern as phosphorus with regard to both the distribution between pools and differences between sites. Only a small fraction of the iodine in the soil is available, and liming is known to further reduce this availability /Fuge and Johnson 1986/. This indicates that the higher relative phosphorus content of the humus layer in Forsmark does not necessarily reflect a greater availability to plants. It is often suggested that the iodine in plants largely originates from the atmosphere /Greger 2004/. The higher relative content (and concentrations of iodine in the producer pool are attributable to the more than 10 times higher concentration of iodine in the tree roots of the conifer forest (most abundant vegetation type) and the 2 to 5 times higher concentration in the bryophytes of the Laxemar-Simpevarp locality. Interestingly, bryophytes obtain all of their element content from the atmosphere, which suggests that part of the difference in iodine content between the sites is due to a higher iodine content on the plant surface in Laxemar-Simpevarp rather than actual accumulation within the plants. Both sites seem to export more iodine than the input as atmospheric deposition. However, relative to the total area there is a larger export in Laxemar-Simpevarp (twice the area of Forsmark) than in Forsmark, and adding the potentially higher atmospheric deposition in Laxemar-Simpevarp suggests that retention of iodine in the catchments at Forsmark is greater than in the catchments at Laxemar-Simpevarp.

Uranium and thorium show a different pattern with low concentrations (Figure 9-2) and content within the biotic pools and the majority of the soil pools (Figure 9-3). There is a difference in the patterns of how uranium is distributed between the pools and how it is exported between the sites. The higher uranium content in the humus layer in Forsmark originates from its somewhat higher concentration in several of the ecosystems, such as in peat on wetlands close to lakes. This is a much more abundant vegetation type in Forsmark than in Laxemar-Simpevarp. Similarly, the higher relative uranium content in biomass originates from high concentrations in the bryophytes on wetlands. Uranium is more mobile than thorium with regard to export at both sites. A net export of uranium and thorium most certainly originates from weathering of soil minerals, for which no estimates are available. The higher export of uranium in Forsmark compared with Laxemar-Simpevarp and the opposite pattern for thorium is more difficult to explain, although thorium seems to be retained in the soils of Forsmark, where the input is higher than the export.

9.3.4 Confidence and uncertainties

The pools have been estimated from a fairly small number of element estimates representing six ecosystems. This means that one or a few misleading samples would have a great impact on the final result. During the analysis, some estimates were partly replaced with more accurate data, i.e. wood phosphorus content. In the end a fairly consistent pattern was found when comparing the sites. Differences in patterns could also partly be explained based on the characteristics of the specific site.

Two fluxes are estimated here: atmospheric deposition and export in streams. Few data describing deposition are available from the site or even from other studies, whereas export has been estimated from site measurements in two and one year for Forsmark and Laxemar-Simpevarp respectively. Little is known about atmospheric deposition for uranium and thorium in general, and for iodine no estimates have been found representing Swedish conditions. However, in the majority of the cases illustrated here, export is much greater than deposition, and the export calculations represent a mean for two years in Forsmark one year in Laxemar-Simpevarp, which suggests that the potential short-term variation is not fully covered in the calculations.

9.3.5 Conclusions

The element distribution among the four compartments mineral soil, humus layer, producers and consumers showed consistent patterns between the sites. Most of the elements found in a higher content in the vegetation were nutrients. The nutrients are found in the group of the non-metals and in the group of metals. Many of the other elements found within the vegetation have analogous behaviour to nutrients and are therefore found accordingly. Other elements seem to be restricted to the fine roots, such as U, Cd and Hg. Generally, small amounts were found in the consumer pool and many elements were found to be below the detection limit.

The mass balances of four elements illustrated some different behavioural patterns, where the water-soluble micronutrient iodine was to a large extent incorporated into the vegetation and also transported further downstream into the lakes. The distribution of the macronutrient phosphorus was similar, but only a small quantity was transported from the terrestrial areas. The mass balance suggested a large retention of phosphorus at the catchment level, where a large part is retained in the vegetation. Thorium and uranium had their largest pools in the mineral soil and to a lesser extent in the humus layer. They showed a less mobile pattern with small amounts found in the vegetation or transported downstream. However, uranium was the element that had the highest export in relation to input of atmospheric deposition, suggesting a high weathering rate compared with thorium. Generally, it would be expected that weathering on these fairly young soils would be somewhat higher than the average for Sweden.

All of the elements are exported to a greater extent in the Laxemar-Simpevarp area than in the Forsmark area, except for uranium. Both phosphorus and iodine are known to precipitate in reactions with $CaCO_3$-rich soils /Greger 2004/, and agricultural land is more abundant in Laxemar-Simpevarp, which may explain a part of the higher retention of phosphorus in Forsmark in comparison with Laxemar-Simpevarp. The different patterns found for uranium and thorium are, however, difficult to explain.

Table 9-9. Mass balance calculations of the total content of phosphorus, iodine, uranium and thorium in all the catchments that were investigated in Forsmark and Laxemar-Simpevarp. The lower second part of the table shows the relative contribution of each pool to the total content and the relative contribution of output and accumulation in relation to the input. A negative sign in the last column suggests that the area has a net export of the element.

Element	Site	Pools (g)				Input (g y^{-1})	Output/Acc. (g y^{-1})	
		Consumers	Producers	Humus/litter	Mineral soil	Deposition	Export	Acc.
P	Fm	17,278	16,199,498	58,034,611	201,473,169	96,735	13,660	83,075
	Sm	168,755	88,612,921	91,702,297	555,548,470	386,017	126,447	259,570
Iodine	Fm	0.3	24,499	166,155	355,546	2,224	9,066	–6,842
	Sm	1.6	292,062	175,907	1,253,654	4,290	35,100	–30,810
Uranium	Fm	0	34,835	247,417	1,789,283	24	3,705	–3,681
	Sm	0	16,815	169,984	3,308,707	43	2,062	–2,019
Thorium$^{2)}$	Fm	0	1,535	30,101	1,855,522	60	25	35
	Sm	0	9,176	24,959	5,684,018	107	424	–317
		Pools (%)				Input (%)	Output/Acc. (%)	
		Consumers	Producers	Humus/litter	Mineral soil	Deposition	Export (of input)	Acc. (of input)
P	Fm	0.01	6	21	73	100	14	86
	Sm	0.02	12	12	75	100	33	67
Iodine	Fm	0	4	30	65	100	408	–308
	Sm	0	17	10	73	100	818	–718
Uranium	Fm	0	2	12	86	100	15,522	–15,422
	Sm	0	0.5	5	95	100	4,807	–4,707
Thorium	Fm	0	0.1	2	98	100	42	58
	Sm	0	0.2	0.4	99	100	395	–295

Table 9-10. Mass balance calculations of the total content of phosphorus in all the catchments that were investigated in Forsmark. Accumulation is calculated as the difference between input (weathering and deposition) and export. The percentage "Output/Acc." is calculated as part of the total input.

Catchment	Pools (g)				Input (g y^{-1})		Output/Acc. (g y^{-1})	
	Consumers	Producers	Humus/litter	Mineral soil	Weathering	Deposition	Export	Acc.
Bolundsfjärden	4,094	3,048,425	14,683,296	43,343,172	24,697	22,339	2,694	44,341
Eckarfjärden	4,458	6,123,181	12,033,810	61,195,567	40,051	25,261	3,049	62,264
Fräkengropen	306	268,007	1,106,084	3,519,464	2,263	1,665	162	3,765
Gällsboträsk	4,504	2,989,802	15,089,104	52,498,115	24,657	25,937	4,632	45,963
Graven	851	753,170	3,291,708	7,727,861	4,127	4,602	647	8,082
Kungsträsket	279	179,217	727,915	3,110,021	1,280	1,482	142	2,620
Lake 2:2	162	107,160	716,590	1,582,454	598	808	52	1,354
N. bassängen	724	816,543	2,744,343	8,331,968	7,393	3,850	399	10,844
Puttan	495	629,681	2,491,571	4,441,701	3,604	2,658	418	5,845
Stocksjön	457	368,999	1,747,630	4,986,360	3,175	2,487	315	5,347
Varmbörsfjärden	947	915,314	3,402,561	10,736,484	5,689	5,646	1,151	10,184
Sum	17,278	16,199,498	58,034,611	201,473,169	117,535	96,735	13,660	200,610
%	0	6	21	73	55	45	6	94

Table 9-11. Mass balance calculations of the total content of phosphorus in all the catchments that were investigated in Laxemar-Simpevarp. Accumulation is calculated as the difference between input (weathering and deposition) and export. The percentage "Output/Acc." is calculated as part of the total input.

Catchment	Pools				Input (g y^{-1})	Output/Acc. (g y^{-1})	
	Consumers	Producers	Humus/litter	Mineral soil	Deposition	Export	Acc.
6_1	30,293	9,072,772	12,758,018	88,046,349	54,090	25,500	92,280
7_1	373	832,181	1,610,613	3,043,646	5,758	1,500	7,711
7_2	14,062	8,125,218	12,393,782	49,642,545	47,010	17,200	71,990
8_1	1,527	1,946,773	3,910,114	25,133,637	13,366	3,500	16,714
9_1	28,092	9,483,544	11,037,537	86,352,805	49,821	22,500	91,620
9_2	9,721	3,011,120	5,000,736	27,963,108	20,717	10,700	31,351
9_3	3,848	881,769	1,358,557	10,375,251	5,992	3,400	9,736
10_1	43,398	25,665,358	23,380,930	165,017,662	92,892	3,547	225,305
10_2	6,033	2,084,623	2,912,332	18,654,268	12,423	5,700	20,994
10_3	3,048	1,815,658	2,447,959	11,352,913	8,623	3,400	14,694
10_4	16,093	8,144,861	3,852,983	19,988,669	27,031	14,000	51,860
10_5	2,021	4,807,965	2,658,149	7,928,323	7,835	2,600	12,778
10_6	6,495	9,615,955	4,103,090	25,687,406	24,018	7,800	43,273
10_7	3,751	3,125,125	4,277,497	16,361,888	16,442	5,100	26,219
Sum	168,755	88,612,921	91,702,297	555,548,470	386,017	126,447	716,526
%	0	12	12	75	46	15	85

Table 9-12. Mass balance calculations of the total content of iodine in all the catchments that were investigated in Forsmark. Accumulation is calculated as the difference between input and export. The percentage "Output/Acc." is calculated as part of the input.

Catchment	Pools				Input (g y^{-1})	Output/Acc. (g y^{-1})	
	Consumers	Producers	Humus/litter	Mineral soil	Deposition	Export	Acc.
Bolundsfjärden	0	3,239	44,676	26,680	514	2,223	–1,710
Eckarfjärden	0	13,893	29,674	126,147	581	2,023	–1,442
Fräkengropen	0	301	3,393	7,287	38	165	–126
Gällsboträsk	0	2,924	40,485	110,276	596	2,364	–1,768
Graven	0	935	10,663	16,255	106	531	–425
Kungsträsket	0	132	1,636	6,551	34	117	–83
Lake 2:2	0	88	1,585	3,348	19	57	–38
N. bassängen	0	839	9,495	16,965	88	429	–340
Puttan	0	696	9,031	9,145	61	309	–248
Stocksjön	0	457	5,484	10,343	57	260	–203
Varmbörsfjärden	0	996	10,033	22,549	130	588	–458
Sum	0	24,499	166,155	355,546	2,224	9,066	–6,842
%	0	4	30	65	100	408	–308

Table 9-13. Mass balance calculations of the total content of iodine in all the catchments that were investigated in Laxemar-Simpevarp. Accumulation is calculated as the difference between input and export. The percentage "Output/Acc." is calculated as part of the input.

Catchment	Pools				Input (g y^{-1})	Output/Acc. (g y^{-1})	
	Consumers	Producers	Humus/litter	Mineral soil	Deposition	Export	Acc.
6_1	0	13,538	22,845	198,348	601	4,919	–4,318
7_1	0	1,717	2,839	6,160	64	523	–459
7_2	0	12,910	23,019	109,167	522	4,537	–4,014
8_1	0	3,794	6,875	46,098	149	1,225	–1,077
9_1	0	12,725	19,440	195,363	554	4,530	–3,976
9_2	0	5,046	8,788	62,320	230	1,883	–1,653
9_3	0	1,489	2,388	23,446	67	545	–479
10_1	0	26,837	50,940	374,165	1,032	8,222	–7,190
10_2	0	3,018	5,128	41,870	138	1,129	–991
10_3	0	2,349	4,307	25,223	96	783	–687
10_4	0	50,797	8,318	59,148	300	2,457	–2,157
10_5	0	67,278	5,558	17,646	87	712	–625
10_6	0	86,014	7,937	58,942	267	2,185	–1,918
10_7	0	4,551	7,525	35,759	183	1,495	–1,313
Sum	2	292,062	175,907	1,253,654	4,289	35,146	–30,856
%	0	17	10	73	100	819	–719

Table 9-14. Mass balance calculations of the total content of uranium in all the catchments that were investigated in Forsmark. Accumulation is calculated as the difference between input and export. The percentage "Output/Acc." is calculated as part of the input.

Catchment	Pools				Input (g y^{-1})	Output/Acc. (g y^{-1})	
	Consumers	Producers	Humus/litter	Mineral soil	Deposition	Export	Acc.
Bolundsfjärden	0	1,167	68,963	109,395	6	856	–850
Eckarfjärden	0	27,773	40,245	672,153	6	977	–971
Fräkengropen	0	213	5,469	37,983	0	64	–63
Gällsboträsk	0	1,622	62,829	534,894	6	1,012	–1,006
Graven	0	1,182	13,709	78,448	1	180	–178
Kungsträsket	0	59	2,134	31,241	0	59	–59
Lake 2:2	0	19	2,211	15,598	0	59	–59
N. bassängen	0	898	14,290	96,588	1	31	–30
Puttan	0	518	16,511	49,011	1	148	–147
Stocksjön	0	249	9,676	53,432	1	99	–98
Varmbörsfjärden	0	1,134	11,380	110,540	1	220	–218
Sum	0	34,835	247,417	1,789,283	24	3,705	–3,681
%	0	1.7	12	86	100	15,522	–15,422

9-15. Mass balance calculations of the total content of uranium in all the catchments that were investigated in Laxemar-Simpevarp. Accumulation is calculated as the difference between input and export. The percentage "Output/Acc." is calculated as part of the input.

Catchment	Pools				Input (g y^{-1})	Output/Acc. (g y^{-1})	
	Consumers	Producers	Humus/litter	Mineral soil	Deposition	Export	Acc.
6_1	0	689	21,768	523,101	6	289	–283
7_1	0	85	2,675	20,237	1	31	–30
7_2	0	654	22,112	303,185	5	250	–245
8_1	0	193	6,463	181,876	1	72	–70
9_1	0	620	18,584	510,472	6	266	–261
9_2	0	257	8,324	168,220	2	111	–109
9_3	0	76	2,265	61,416	1	32	–31
10_1	0	1,141	50,249	972,919	10	495	–485
10_2	0	147	4,876	111,305	1	66	–65
10_3	0	109	4,101	68,539	1	46	–45
10_4	0	3,091	8,248	89,762	3	144	–141
10_5	0	4,220	5,397	47,769	1	42	–41
10_6	0	5,312	7,760	149,292	3	128	–126
10_7	0	221	7,161	100,613	2	88	–86
Sum	0	16,815	169,984	3,308,707	43	2,062	–2,019
%	0	0.5	5	95	100	4,807	–4,707

Table 9-16. Mass balance calculations of the total content of thorium for all the catchments that were investigated in Forsmark. Accumulation is calculated as the difference between input and export. The percentage "Output/Acc." is calculated as part of the input.

Catchment	Pools				Input (g y^{-1})	Output/Acc. (g y^{-1})	
	Consumers	Producers	Humus/litter	Mineral soil	Deposition	Export	Acc.
Bolundsfjärden	0	236	7,130	404,660	14	6	8
Eckarfjärden	0	691	7,709	537,609	16	6	10
Fräkengropen	0	27	511	31,665	1	0	1
Gällsboträsk	0	229	8,049	506,978	16	7	9
Graven	0	80	1,301	74,880	3	1	1
Kungsträsket	0	11	452	30,557	1	0	1
Lake 2:2	0	6	442	15,878	0	0	0
N. bassängen	0	75	1,208	67,278	2	1	1
Puttan	0	53	788	38,771	2	1	1
Stocksjön	0	38	763	45,287	2	1	1
Varmbörsfjärden	0	89	1,749	101,958	3	2	2
Sum	0	1,535	30,101	1,855,522	60	25	35
%	0	0.1	1.6	98	100	42	58

9-17. Mass balance calculations of the total content of thorium in all the catchments that were investigated in Laxemar-Simpevarp. Accumulation is calculated as the difference between input and export. The percentage "Output/Acc." is calculated as part of the input.

Catchment	Pools				Input ($g\ y^{-1}$)	Output/Acc. ($g\ y^{-1}$)	
	Consumers	Producers	Humus/ litter	Mineral soil	Deposition	Export	Acc.
6_1	0	496	1,605	946,570	15	59	–44
7_1	0	50	118	18,230	2	5	–4
7_2	0	439	2,093	478,208	13	52	–39
8_1	0	124	155	51,239	4	14	–10
9_1	0	463	1,514	945,627	14	55	–41
9_2	0	171	365	286,593	6	32	–27
9_3	0	53	113	113,059	2	9	–7
10_1	0	946	13,082	1,824,408	26	93	–67
10_2	0	105	324	197,345	3	0	3
10_3	0	80	273	114,727	2	11	–8
10_4	0	1,540	2,302	175,739	8	39	–31
10_5	0	1,994	1,015	80,763	2	8	–6
10_6	0	2,564	1,542	298,506	7	29	–22
10_7	0	152	458	153,006	5	19	–15
Sum	0	9,176	24,959	5,684,018	107	424	–317
%	0	0.2	0.4	99	100	395	–295

10 Postglacial terrestrial development and vegetation change

The long-term ecosystem development in the inshore land and sea areas of Fennoscandia is driven mainly by two factors: climate change and shoreline displacement. A third factor affecting ecosystems is human land use, which has become more and more important over time as the human population has increased and the appropriation of resources has increased exponentially.

The climate changed repeatedly during the Quaternary period, thereby changing the conditions for biota that to a high degree define the ecosystems. Such climatic changes have directly changed the conditions for ecosystem formation, e.g. mire and bog complexes, and have caused north- and south-ward migration of species and ecological communities. Changes of species distributions have the potential to affect entire ecosystems, e.g. the emergence or disappearance of species that may have a key function in the ecosystem, such as the megaherbivores that are thought to have kept the forests fairly open, or a predator that may directly alter the food web and thereby the whole ecosystem. In this perspective, human land use is also an important component that has in many ways shaped the landscape of today.

The second important factor, shoreline displacement, has strongly affected both Forsmark and Laxemar-Simpevarp since the last deglaciation and is still causing a relatively predictable change in the abiotic environment, e.g. in water and nutrient availability. It is therefore appropriate to describe the origin and succession of some major ecosystem types in relation to shoreline displacement. The sections below both have a general perspective on the long-term change of climate, soil, fauna, ecosystem and human land use in Fennoscandia, and the regional perspectives of Forsmark and Laxemar-Simpevarp.

10.1 Postglacial development of vegetation

The vegetation development in southern Sweden following the last deglaciation was primarily determined by climatic changes and the formation of new land areas, but human activities have also influenced large-scale vegetation development, especially during the last few millennia. Shortly after the retreat of the ice sheet, which started in southernmost Sweden in c 15,000 BC, the landscape was free of vegetation and can be characterized as a polar desert. Relatively soon, the ice-free areas were colonized, first by lichens and mosses, then by tolerant grasses and herbs. Pollen investigations from southern Sweden have shown that a sparse birch (*Betula* sp) forest covered the landscape soon after the deglaciation /e.g. Björck 1999/.

During the period called the Younger Dryas (c 11,000–9500 BC) there was a decrease in temperature and the climate became arctic. Large areas of the deglaciated parts of Sweden were affected by permafrost, and much of the previously established flora and fauna disappeared. Only the most tolerant species remained and herb tundra developed. At the beginning of the Holocene c 9500 BC, the temperature increased again and southern Sweden was covered by forests, first dominated by birch and later by Scots pine (*Pinus sylvestris*) and hazel (*Corylus avellana*).

Northern Sweden was deglaciated during the early part of Holocene when the climate was relatively warm. These areas were therefore covered with forest, mainly consisting of birch and Scots pine, shortly after deglaciation. There was a cooling of the early Holocene climate during the so-called Preboreal oscillation, which was a 150 year long cooling period /Björck et al. 1996/. During the mid-Holocene, between 7,000 and 5,000 years ago, the summer temperature in southern Sweden was approximately 2°C warmer than at present. Forests with lime (*Tilia cordata*), oak (*Quercus robur*) and elm (*Ulmus glabra*) covered large parts of southern Sweden.

These trees then had a much more northerly distribution than in the present day. However, cold events occurred also during the warm mid-Holocene. Results from Greenland ice cores presented by /Alley et al. 1997/ show that a cold event, half the amplitude of the Younger Dryas, occurred around 6200 BC. In a study of the Holocene climate of northern Sweden, /Karlén et al. 1995/ recognized more than ten small oscillations between a relatively warm and cold climate. The summer temperature during the warm periods was generally 1ºC warmer than at present, and during the cold periods it was 1 ºC colder than at present.

After the warm mid-Holocene, the temperature decreased and the forests have subsequently become more dominated by coniferous trees. Norway spruce (*Picea abies*) spread from northernmost Sweden southward during the Holocene. This species has not yet spread naturally to parts of Skåne and the Swedish west coast /e.g. Lindbladh 2004/. /Davis et al. 2003/ reconstructed the Holocene climate in Europe from pollen data. They concluded that the warmer climate during the mid-Holocene was restricted to north-western Europe, whereas the climate further south was similar to or colder than that of today. The ecological history of Sweden during the last 15,000 years has been reviewed by e.g. /Berglund et al. 1996a/. In Figure 10-1, tree pollen diagrams from three Swedish regions show the vegetation succession from the last deglaciation to the present.

During the past few thousand years, the composition of the vegetation has changed not only due to climatic changes and the formation of new land areas, but also due to human activities. In southern Sweden, the introduction of agriculture and the subsequent opening of the landscape started c 5,000 years ago. It is often assumed that Sweden was more or less covered by forest before the introduction of agriculture. However, /Vera 2000/ suggested that grazing animals kept the European landscape relatively open. Some of the grazing animals which were common in the early Holocene have decreased or disappeared completely. /Lindbladh et al. 2003/ have suggested that fires also kept some forest types more open before humans started to have an impact on the forests in northern Europe.

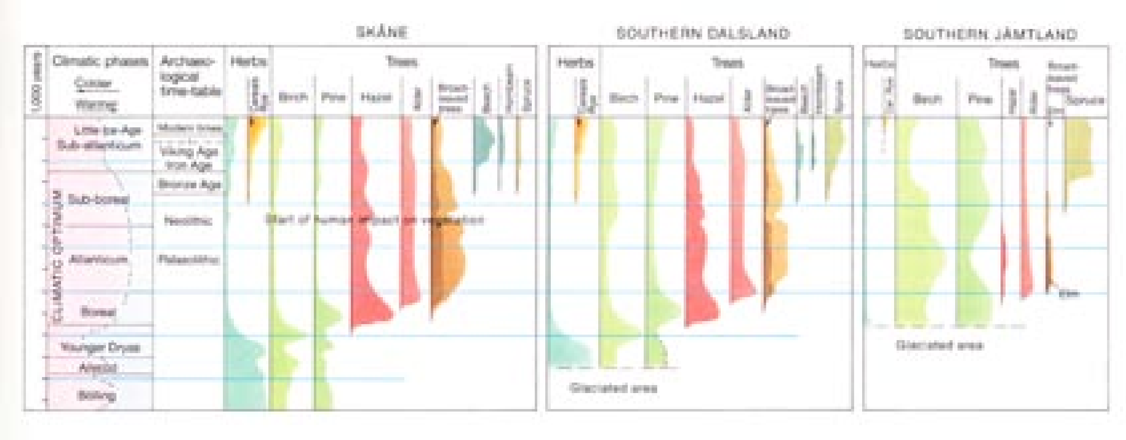


Figure 10-1. Pollen diagram showing how the composition of vegetation has changed from the last deglaciation to the present. The diagrams were made after analyses of sediment cores from Skåne, Dalsland, and Jämtland. The past summer temperature was somewhat higher than the present, something which is reflected by higher frequencies of pollen from broad-leafed trees (c 5,000–8,000 years ago). In southern Sweden agriculture was introduced in c 3000 BC, which is shown as an increase in the frequency of pollen from herbs /from Fredén (ed.) 2002/.

10.1.1 The Forsmark area

When the latest deglaciation in Forsmark took place in approximately 8800 BC, the closest shore was situated c 100 km to the west of Forsmark. At that time, the Forsmark area was situated c 150 m below the surface of the Yoldia Sea /Söderbäck (ed.) 2008/. Since the major part of the Forsmark regional model area was covered by water until c 500 BC, the post-glacial development of the area is determined mainly by the development of the Baltic basin and by shoreline displacement.

At around 500 BC, a few scattered islands situated in the western part of the regional model area were the first land areas to emerge from the brackish water of the Bothnian Sea. The surface of these first islands was covered by sandy till and exposed bedrock, i.e. similar to the present situation on the islands outside Forsmark area. Palaeo-ecological studies from the Florarna mire complex, situated c 30 km west of the regional model area indicate a local humid and cold climate at approximately this time /Ingmar 1963/.

At 0 BC, the Bothnian Sea still covered most of the Forsmark area, whereas the islands in the western part of the regional model area had expanded in size. Land areas currently covered with peat had emerged, and at that time these newly isolated basins were small and shallow freshwater lakes/ponds, similar to the near-shore lakes which can be found in the area today. The apparent isolation of Lake Bruksdammen in the western part of the area around 0 BC is an artefact caused by the use of today's lake thresholds when constructing the map; the lake was probably created by man in the 17th century by damming the Forsmarksån river /Brunberg and Blomqvist 1998/.

At 1000 AD, the mainland had expanded further in the south-western part of the area. The isolation process of the Lake Eckarfjärden basin was initiated, but the bay still had an open connection with the Baltic in the northern part /cf. Hedenström and Risberg 2003/. The area west of Lake Eckarfjärden 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 (Figure 10-2) constituted some small islands in the east, exposed to waves and erosion.

At 1500 AD, a considerable part of the regional model area had emerged from the Baltic and several freshwater lakes were isolated, e.g. Lake Eckarfjärden and Gällsboträsket. A shallow strait connected the bays that today are Lake Bolundsfjärden and Lake Fiskarfjärden. The northern part of this archipelago was heavily exposed to wave action, whereas the southern part was relatively protected. The area covered by clayey till at Storskäret formed a large island, partly protected from wave exposure by the Börstilåsen esker. A hundred years later, the strait between Bolundsfjärden and Fiskarfjärden had been cut off, and there were two bays with different conditions. At around 1650 AD, the major part of the area was situated above sea level.

The post-glacial development of ecosystems in the Forsmark area principally been determined by the climate, the development of the Baltic basin and shoreline displacement, as described above and in Chapter 4. The first terrestrial ecosystems appeared around 500 BC, and the succession of both the terrestrial and aquatic ecosystems have in all essentials followed the general patterns outlined above.

The vegetation development

In order to describe the Holocene vegetation history of the area during a longer timespan, the area for collecting data must be expanded to include more elevated regions such as the western part of the county of Uppland. /Karlsson 2007/ has recently compiled published investigations on pollen analyses from Uppland, together with results from stratigraphical investigations performed in connection with archaeological investigations for the construction of 90 km of new highway (E4) in northern Uppland. The following description is based mainly on the associated compilation of 12 pollen diagrams /Karlsson 2007/, and focuses on the vegetation history of Uppland during the Stone Age (c 5500–2300 BC). A palaeo-ecological description of South-Central Sweden /Berglund et al. 1996a/ is also used for the regional description.

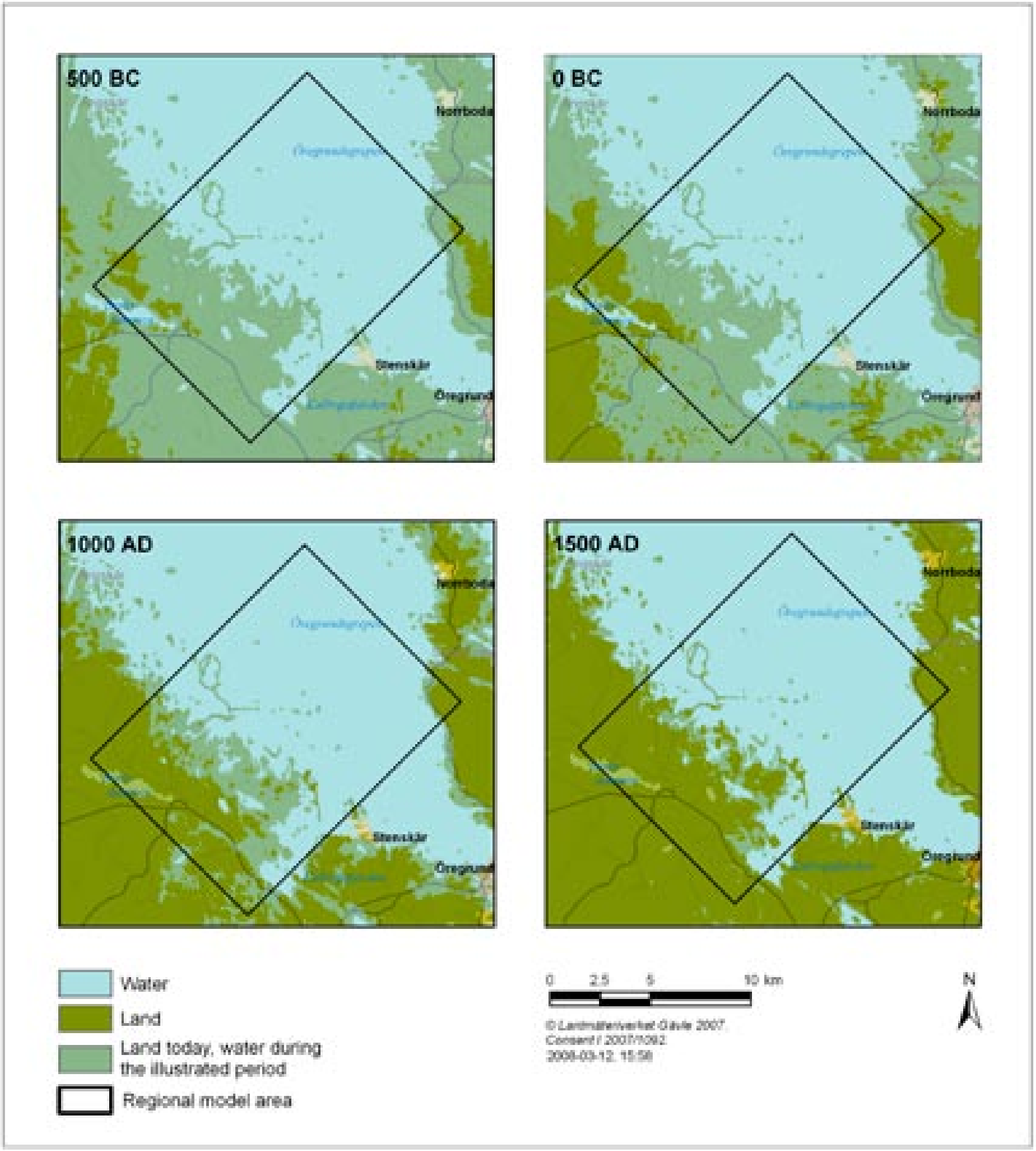


Figure 10-2. *The distribution of land and sea in the Forsmark area at 500 BC, 0 BC, 1000 AD and 1500 AD. From /Söderbäck (ed.) 2008/.*

In western Uppland, the first areas to emerge were mainly covered by till, bare bedrock and eskers. In all pollen diagrams, Scots pine and birch are the dominant trees when the sites were located in the outer archipelago, while a mixed deciduous forest containing e.g. oak, aspen (*Populus tremula*) and lime spread at sites located in the inner archipelago. Along the shores and in bays, alder (*Alnus*) and willow (*Salix*) were common, while in sheltered positions on fine-grained Quaternary deposits a temperate and nutrient-demanding tree flora consisting of elm and hazel was widespread.

Flat rocks and crevices close to the shore probably hosted a light-demanding flora such as common juniper (*Juniperus communis*), heather (*Calluna vulgaris*) and sheep sorrel (*Rumex acetosella*). A pioneer shrub found from the Mesolithic and onwards is sea-buckthorn (*Hippophaë rhamnoides*), which is one of the typical shrubs along the Forsmark coast today. Sea-buckthorn is very sensitive to competition from other plants and needs to colonize unweathered minerogenic deposits. These conditions are only found where new, unweathered and uncolonized land areas emerge, i.e. where the rate of shore displacement is faster than approximately 5 mm/year.

As the land areas grew and the islands became part of the mainland, the number of pollen taxa found in the sediments increased, reflecting that a more diverse flora was developing at the sites. An event that is often identified in pollen diagrams from north-western Europe is the decline of elm pollen at c 3000 BC, known as the elm decline /Huntley and Birks 1983/. A number of causes have been suggested for the elm decline: climatic changes, elm disease, human activity or a combination of these. The elm decline can be traced in more than 50% of the pollen diagrams from Uppland and is dated to c 2500 BC /Karlsson 2007/.

Only few investigations are available to provide information on the local vegetation history. At the Hållnäs peninsula, c 35 km north of the Forsmark regional model area, biostratigraphical investigations were performed in connection with archaeological investigations /Ranheden 1989/. These investigations indicate traces of forest clearing from c 600–700 AD. Extensive land use and settlements from the Viking age and medieval period were identified in the fossil record, indicating that humans have been occupying the archipelago as new land has emerged from the Baltic.

A pollen investigation of sediment collected in the Kallrigafjärden has been performed /Bergkvist et al. 2003/. The sampling site was located close to the outlet of the Olandsån River, which means that the pollen record in the sediments will give a regional vegetation history. Norway spruce is present in the bottom layer of the sediment, indicating that the whole sediment sequence was deposited after the immigration of Norway spruce at c 0 AD/BC /Berglund et al. 1996/. Heather and sea-buckthorn pollen reflect the vegetation at the shores. High values of lime pollen may indicate that this species was important for fodder production and was therefore favoured by humans /Bergkvist et al. 2003/. Other traces of humans are corn (*Hordeum* sp) from far down in the sediment, indicating cultivation within the area. There are no radiocarbon dates for the analyzed sediments from Kallrigafjärden, so no absolute ages are known.

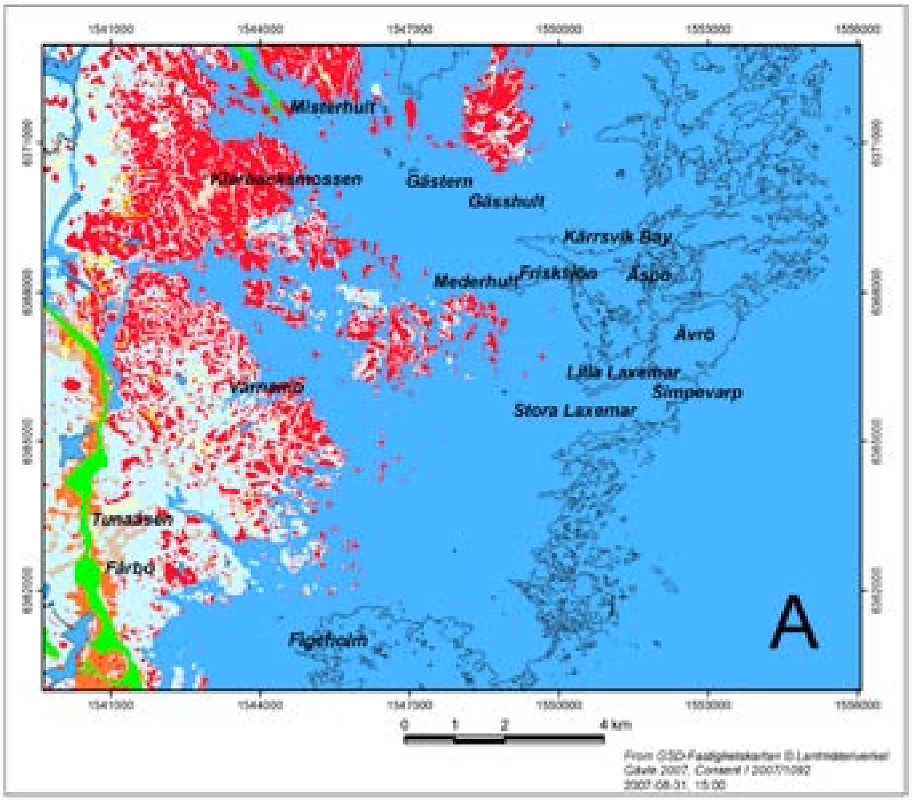
Weathering and leaching of carbonates will occur under all carbonate-rich vegetation types /Ingmar and Moreborg 1976/, leading to a gradual change to a flora adapted to environments with a lower pH. Accordingly, there will be a zone of vegetation favoured by high pH along the coast, and this zone will continuously move as new land areas emerge from the sea

10.1.2 The Laxemar-Simpevarp area

The last deglaciation in the Laxemar-Simpevarp area took place c 14,000 years ago, and the highest shoreline in the region is located c 100 m above the present sea level. Thus, the whole Laxemar-Simpevarp area is situated below the highest shoreline, since the highest point in the area is situated c 50 m above the present sea level. The sea level dropped fast during the end of the Baltic Ice Lake, from c 66 metres above present sea level (metres above sea level) around 10,000 BC to less than 20 metres above sea level just over 1,000 years later. Accordingly, the first islands in the area emerged from the sea around 9400 BC.

The Yoldia Sea stage (9500–8800 BC) was characterized by regressive shoreline displacement, whereas the onset of the Ancylus Lake stage around 8700 BC was characterized by a transgression with total amplitude of c 11 m. shows the former shoreline in the Laxemar-Simpevarp area at three different occasions during the Holocene. At around 8000 BC, i.e. in the middle of the lacustrine Ancylus Lake stage, the shoreline was situated just above 20 metres above sea level, which means that the western part of the Laxemar-Simpevarp regional model area was free of water. Between 8000 BC and 5000 BC, i.e. the first part of the Littorina Sea stage, shoreline displacement was mostly regressive, although there are indications of several minor transgressions during that period. At 5000 BC, when the shoreline was situated c 15 metres above sea level, the central parts of the regional model area were free of water, but the fissure valleys still constituted long and narrow coastal bays which intersected the area. At 2000 BC, most of today's terrestrial areas had emerged from the sea and the coastal bays decreased considerably in size. Since 0 BC, the sea level has dropped c 3 m, but this has resulted in only minor changes in the distribution of land and sea in the regional model area.

Similarly to the Forsmark area, the postglacial development of ecosystems in the Laxemar-Simpevarp area is principally determined by the climate, the development of the Baltic basin and the shoreline displacement, as described above and in Chapter 4. The first terrestrial ecosystems appeared around 9000 BC, and the succession of both the terrestrial and aquatic ecosystems has in all essentials followed the general patterns outlined above. Site-specific information that can be added to the general successional trajectories includes regional vegetation history, the local and regional lake ontogeny and the development of areas used as arable land.



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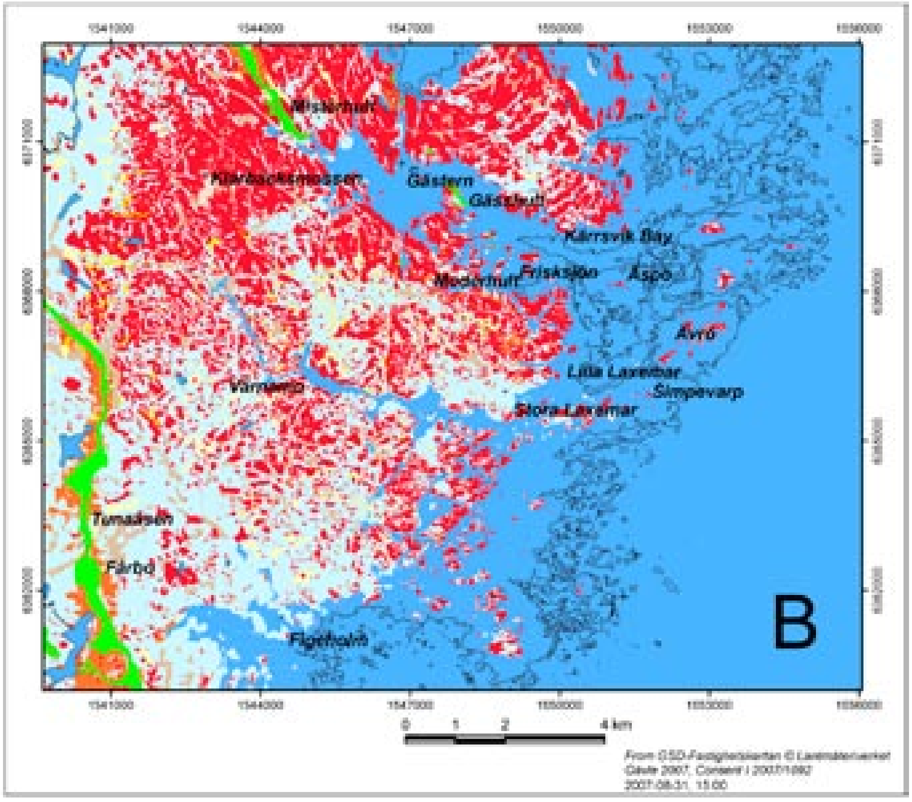

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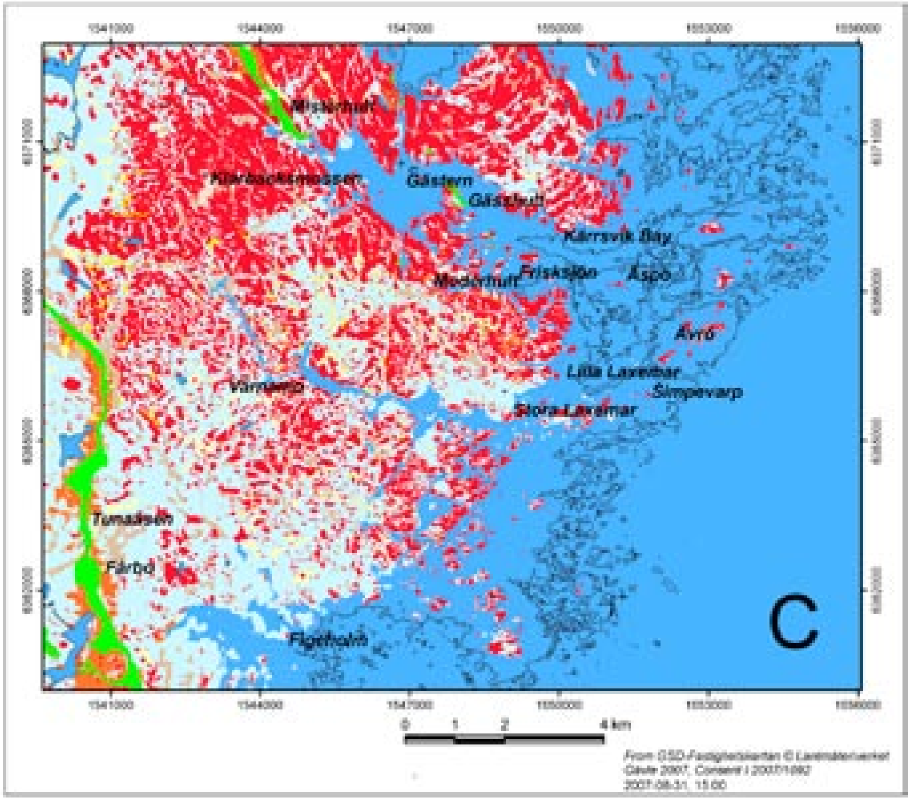

***Figure 10-3.** Distribution of land and sea in the Laxemar-Simpevarp area at three different times during the Holocene, A) 7800 and 8650 BC, B) 3900 BC, C) 1100 BC. The sea level was 19 (A), 12 (B) and 5 (C) meters higher than at present at the three times shown on the maps. Figure A represent two different occasions, one before and one after the Ancylus transgression. From /Söderbäck (ed.) 2008/.*

The vegetation development

Stratigraphical investigations of pollen from Blekinge show the succession of terrestrial plants in south-eastern Sweden from the latest deglaciation to the present /Berglund 1966/. Shortly after the Laxemar-Simpevarp area was deglaciated in c 12,000 BC, it was characterized by tundra vegetation dominated by herbs and bushes and a low coverage of trees. During the following Alleröd chronozone) a sparse birch and Scots pine forest dominated the vegetation. In southern Sweden, the following cold Younger Dryas chronozone was characterized by tundra vegetation, which is reflected in a high proportion of wormwood (*Artemisia*) pollen. In stratigraphical studies in the Laxemar-Simpevarp area, /Lagerbäck et al. 2004b/ found evidence of tundra conditions during the Younger Dryas.

At the beginning of the Holocene, c 9500 years BC, the temperature increased and south-eastern Sweden was first covered by forests dominated by birch and later by forests dominated by Scots pine and hazel. During the period 7000–4000 BC, forests consisting of lime, oak and elm covered south-eastern Sweden /e.g. Berglund 1966, Küttel 1985/. The spread and establishment of beech (*Fagus sylvatica*) and Norway spruce in southern Sweden has been investigated in several studies /Björkman 1996, Bradshaw and Lindbladh 2005/. Norway spruce spread from the north and reached the Laxemar-Simpevarp area less than 1,000 years ago /Lindbladh 2004/. It is possible that domestic animals were involved in the spread of spruce, since grazing animals avoid spruce /Björkman 1996/. Beech has spread over southern Sweden during the last 4,000 years. The species was common in eastern Småland two thousand years ago, but has since disappeared from that area /Bradshaw and Lindbladh 2005/. The decline of beech was probably caused by human activities.

A pollen investigation covering the last c 1,500 years has been carried out on sediments from two lakes situated 20 and 25 kilometres west of Fårbo /Aronsson and Persson, unpublished data/. The results show an increase of *Juniperus* (juniper) and *Cerealea* (corn) c 1,200 years ago, which indicates that areas used as arable land and for pasture increased during that time.

10.2 Postglacial development of soil, organic carbon and nitrogen pools

When new land is exposed, plant colonization takes place and organic matter is added to the soil through litter fall. The accumulation of soil organic matter depends on the litter input and the decomposition of soil organic matter. Over time these two processes come into a state of equilibrium where decomposition balances litter input, and as a consequence the organic carbon stock in the soil fluctuates around a constant value. The time required for this equilibrium to establish itself varies, but may be up to 10,000 years /Birkeland et al. 1999/. For Scandinavian forest soils this time has been reported to be approximately 2,000 years /Liski et al. 1998/. However, disturbances such as forest fires or other catastrophic events as well as forest management may temporarily upset this equilibrium. The size of the carbon and nitrogen stocks depends on environmental conditions such as climate, soil moisture and soil fertility. These factors may influence litter input and the decomposition rate to different degrees. On moist sites the decomposition rate is inhibited, whereas forest growth and litter fall may be high, which may result in a higher accumulation rate. The distribution of the accumulated organic matter in the soil profile depends on the soil type that is developed. For example, Podzol soil types have large amounts of organic matter concentrated in the organic horizon, whereas in Cambisol types the organic matter is distributed more evenly in the upper soil profile due to bioturbation. This means that if the aim is to investigate variation in carbon stock, the soil type must be considered.

Reference field data from the National Forest Soil Inventory (NFSI) from the period 1993–2002 was used to describe the development of carbon and nitrogen stocks in forest soil during the postglacial period and to estimate the time required for the stocks to reach a steady state. A total of 4,697 sites in the NFSI (Figure 10-4) were sampled in the mineral soil, and the soil carbon and nitrogen stocks were estimated to a depth of 50 cm in the mineral soil for these sites. From this data, a subset of sites on Podzol type soils (Iron Podzol, Humic Podzol and transitional forms between Podzol and Cambisol) which represents the dominant forest soil types was used in the analyses.

Soil samples were taken from the forest floor and from up to three layers in the mineral soil: the top of the B horizon, 45–55 cm from the top of the organic layer (B–C horizon) and 55–65 cm from the top of the mineral soil (C horizon). The soil carbon stock for each sampled soil layer was calculated using the following function:

$$C_{pool} = \sum_{\text{i=soil layer}} (C_{conc}/100) \times BD \times DEPTH_i \times \left(1 - C_{stone}/100\right)$$

where C_{pool} is the carbon pool (kg m^{-2}), C_{conc} is the carbon concentration (%), BD is the bulk density (kg m^{-3}), DEPTH is the layer depth (m), and C_{stone} is the stone content (%). For nitrogen stocks, nitrogen replaced carbon concentrations in the function. The bulk density was determined from functions by /Nilsson and Lundin 2006/. The stone content was estimated from inventory data by the so-called Viro's rod penetration method /Viro 1952/. To estimate the total stock, the stock for the layers between the sampled soil layers was estimated by interpolation, and finally the stocks for all layers down to 50 cm were added together.

The soil age was determined based on shoreline displacement functions developed by /Påsse 1997/, which were determined for 28 sites in Sweden. These functions give the elevation of the sea as a function of age before present (before 1950). For each site in the NFSI, the function associated with the most closely located site in /Påsse 1997/ was applied. The elevation for each site in the NFSI was taken from the Swedish digital terrain model (Lantmäteriverket GSD) and this elevation was inserted into the shoreline displacement functions. The equation was solved using the SAS statistical software SAS 9.1 (SAS Institute Inc.) to get the age since the site was exposed. The soil age for areas above the highest shoreline was assumed to be the age since ice withdrawal, as given by the National Atlas of Sweden /Fredén (ed.) 2002/. The analyses were limited to sites with a maximum age of 10,000 years, since it was the dynamics in the first millennia that was of the greatest interest.

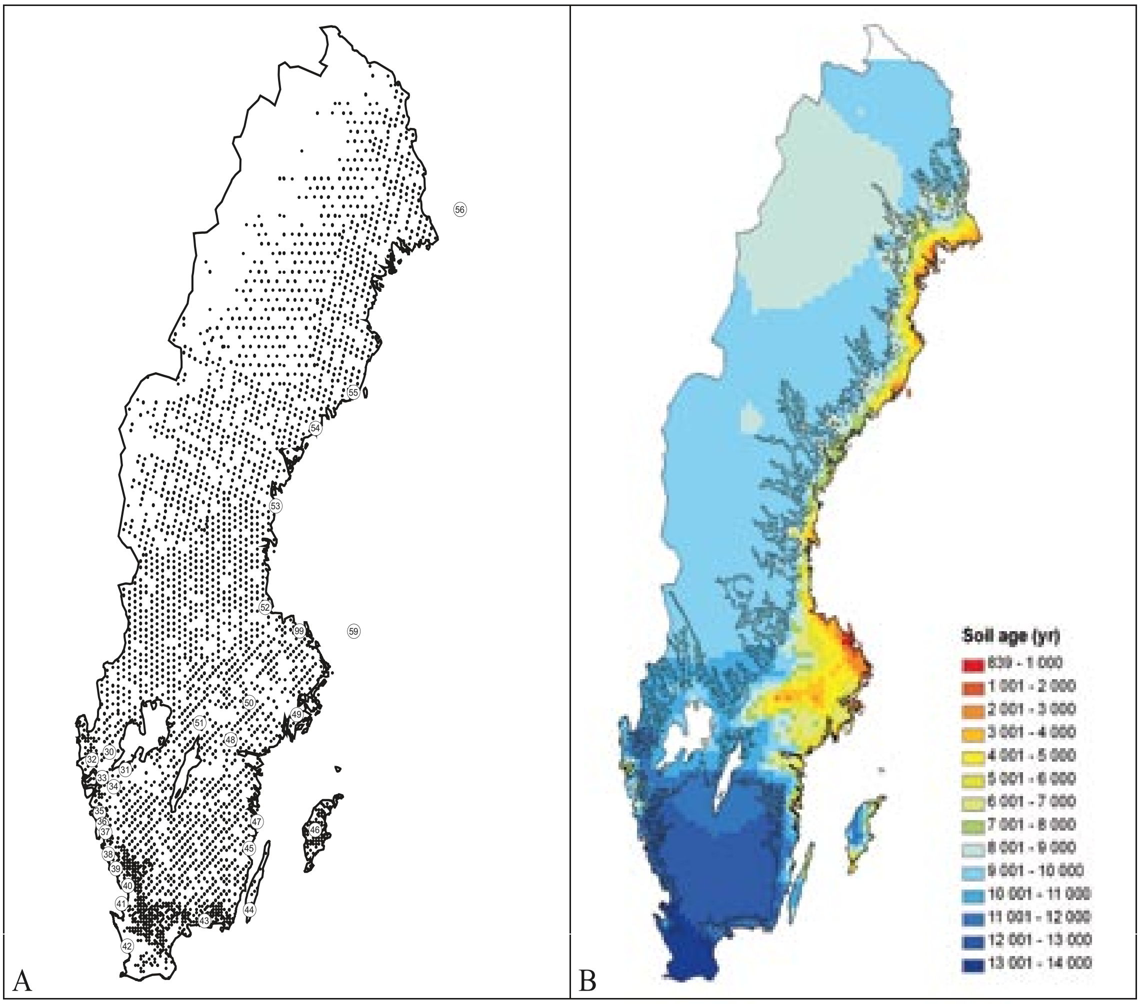

Figure 10-4. *A) Plots in National Forest Soil Inventory, where soil carbon stock has been estimated to a depth of 65 cm (4,697 plots) and 28 sites with shoreline displacement functions /Påsse 1997/. B) Soil age distribution in Sweden and the highest shoreline.*

The number of NFSI sites in the youngest age classes was very small, which can be seen in the frequency distribution of the age classes (Figure 10-5). The young areas were mainly found along the coast of Uppland, around Lake Mälaren and in the northernmost part of the Swedish coastline ((Figure 10-4B). The oldest soils were found in the southern part of Sweden, where the retreat of the ice cover was earliest and where the land was never submerged beneath the sea. The relationships between the carbon stocks in the soil and the age of the soil were weak, due to the great variability (Figure 10-6). Variability was even greater for the nitrogen stocks (Figure 10-7). However, the results indicated an increase in total carbon stock for Podzol soils during the first c 2,500 years, after which it remained stable. For carbon, there was greater variation in mineral soil than in the humus layer (Figure 10-6 (C and D)). For the humus layer (Figure 10-6 (C)) there was an increase in stocks during the first c 2,500 years, whereas for the mineral soil there was too much scatter for any pattern to be seen. The NFSI plots within each of the age classes were rather evenly distributed geographically, and the results were not associated with any climate gradient. For Histosol soils, data were scarce for the youngest age classes, but the carbon and nitrogen stocks on these young sites were quite large. This might be due to the gradual formation of peat soils as sea bays are transformed into lakes and become filled with vegetation such as Sphagnum mosses. At the time when the site rises above sea level, a large amount of organic matter might already have formed.

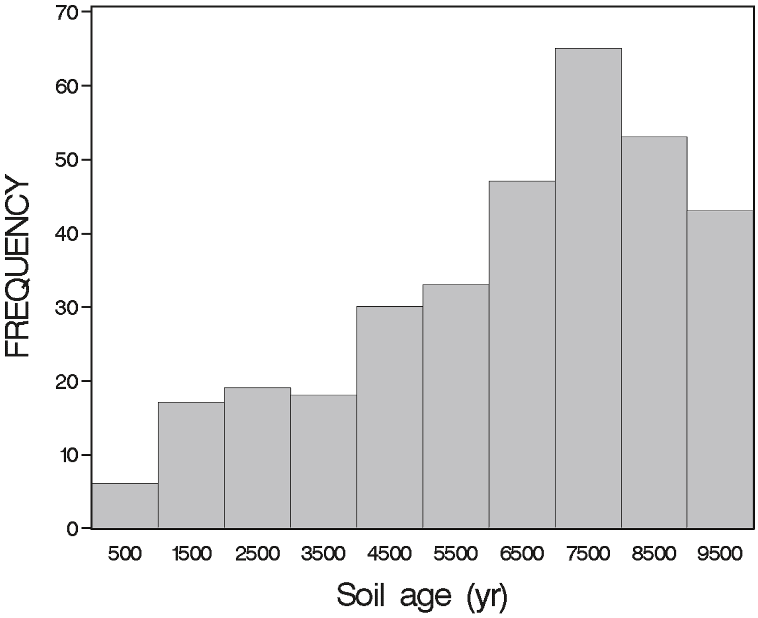

Figure 10-5. *Frequency distribution of soil age for plots in the National Forest Soil Inventory located on till parent material. Only plots below the highest shoreline are included.*

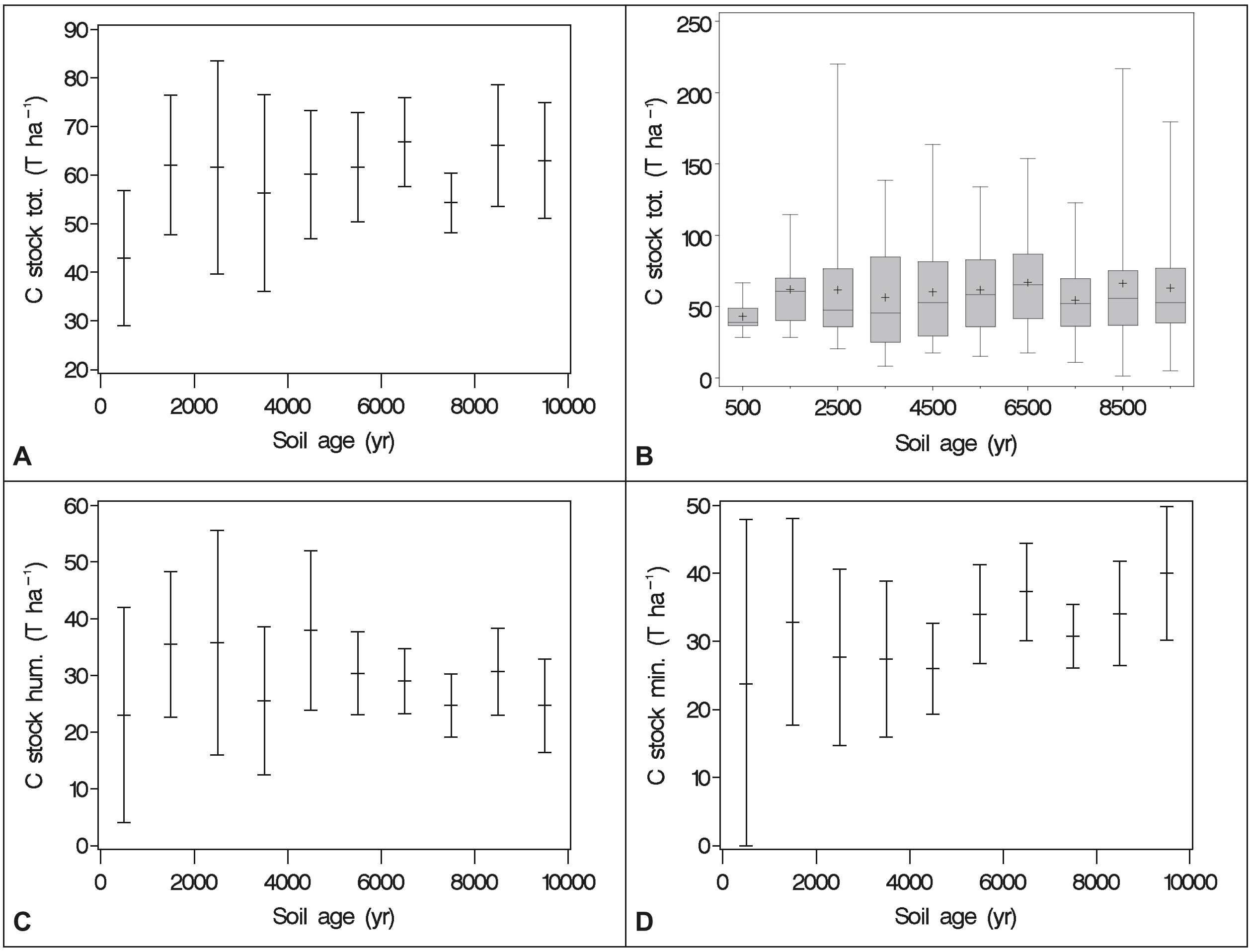

Figure 10-6. *Soil carbon stock in Podzols versus soil age including 95% confidence intervals. (A) and (B) represent the total stock, (C) the stock in the humus layer and (D) the stock in the mineral soil to a depth of 50 cm.*

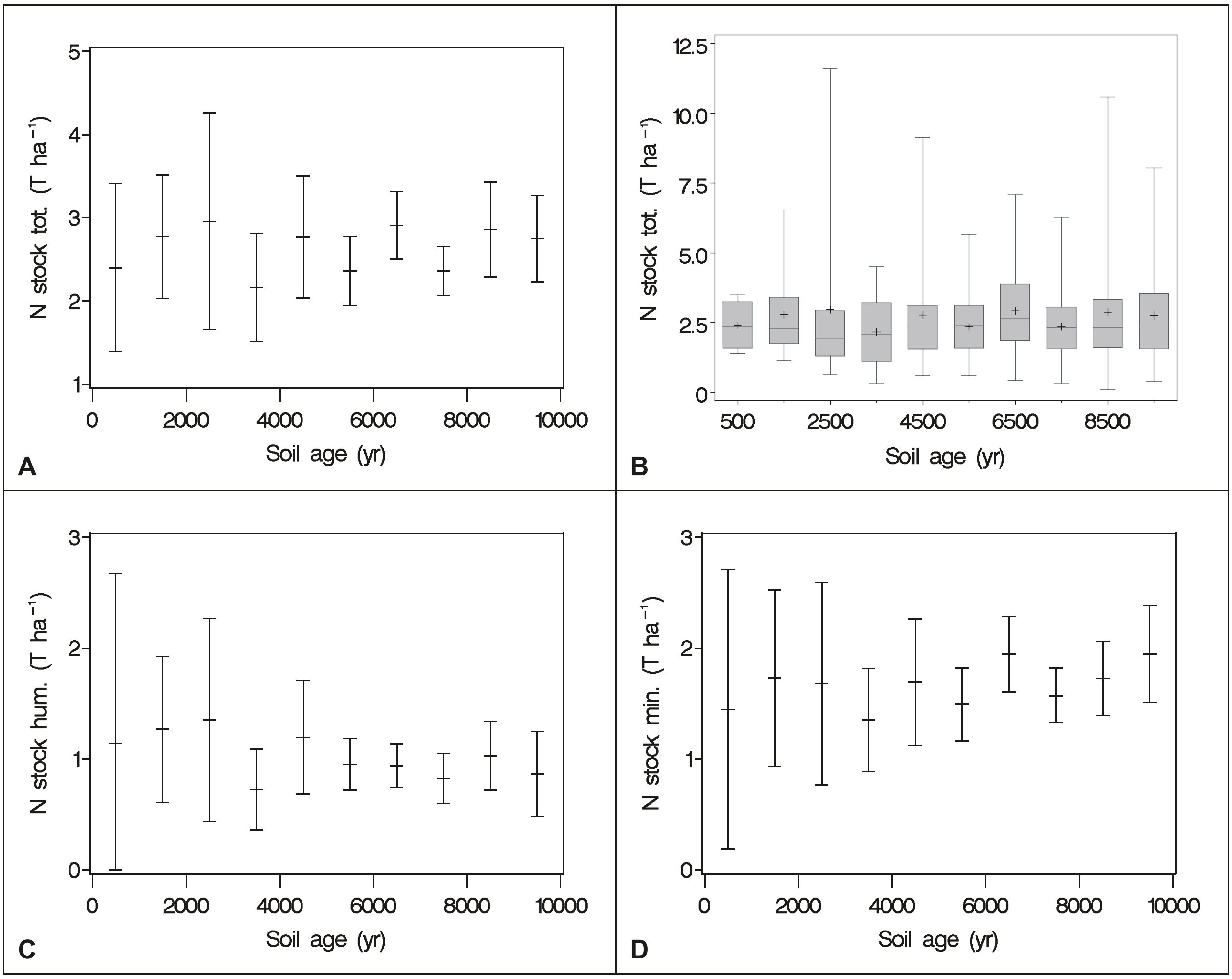

Figure 10-7. *Soil nitrogen stock in Podzols versus soil age including 95% confidence intervals. (A) and (B) represent the total stock, (C) the stock in the humus layer and (D) the stock in the mineral soil to a depth of 50 cm.*

The relationships between concentrations of carbon and nitrogen in the sampled mineral soil horizons and soil age are presented in Figure 10-8 and Figure 10-9. For the concentrations in the B horizon, the results were similar to the total stocks, although an increase in carbon and nitrogen concentrations at older ages could be seen as well. In the B–C horizon the relationship with age was similar, although variability was greater. This might have been caused by a larger heterogeneity in B–C data, since these samples may consist of material from different horizons. For the C horizon there was an increase in carbon and nitrogen concentrations until an age of c 6,000 years, although there were some extreme values for ages of 1,500 and 5,500 years. This may indicate a slower dynamic between input to this layer and decomposition of organic matter for the deeper horizons, and a longer period before an equilibrium is reached. The quality of the organic matter decreases with depth, and it is therefore decomposed at a slower rate /Bosatta and Ågren 1996/.

The results in this study indicate that the total carbon and nitrogen stocks in Podzol soils reach equilibrium after approximately 2,500 years. In deeper soil layers the carbon concentration seems to increase for c 6,000 years and then level off. The concentrations of carbon and nitrogen produced slightly better results than the estimated stocks. The results are uncertain though, because of the large variability in the data.

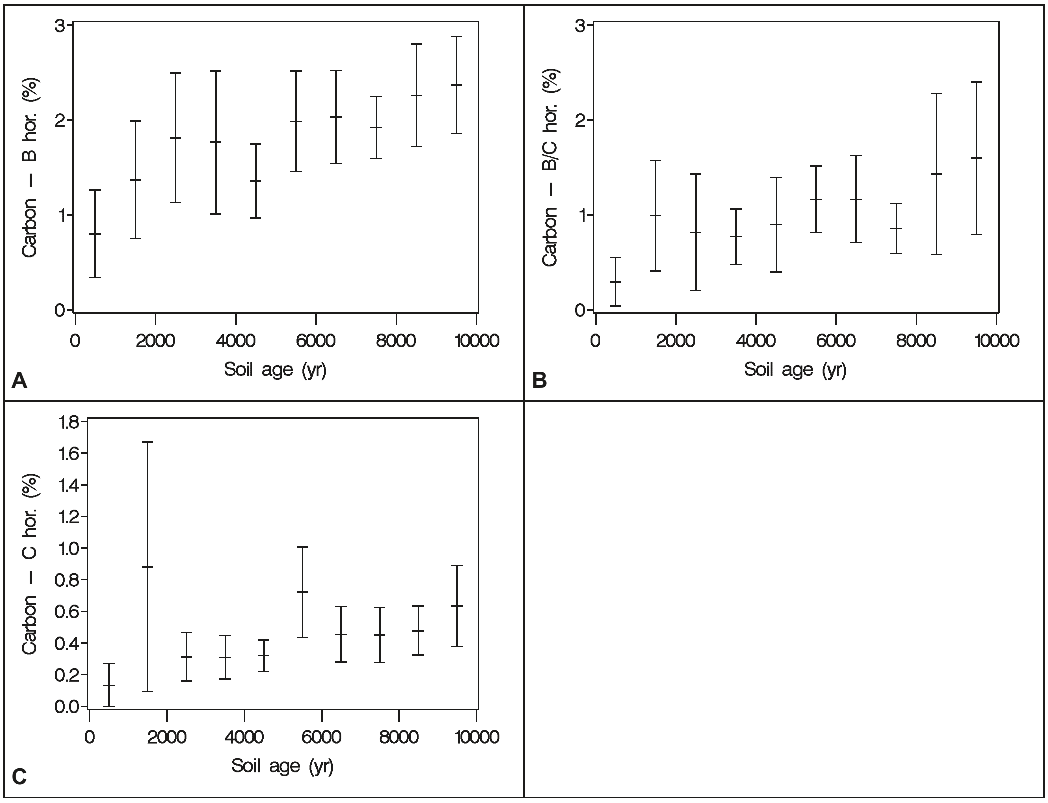

Figure 10-8. Soil carbon concentration in Podzols versus soil age including 95% confidence intervals. (A) represents the B horizon, (B) the B–C horizon, and (C) the C horizon.

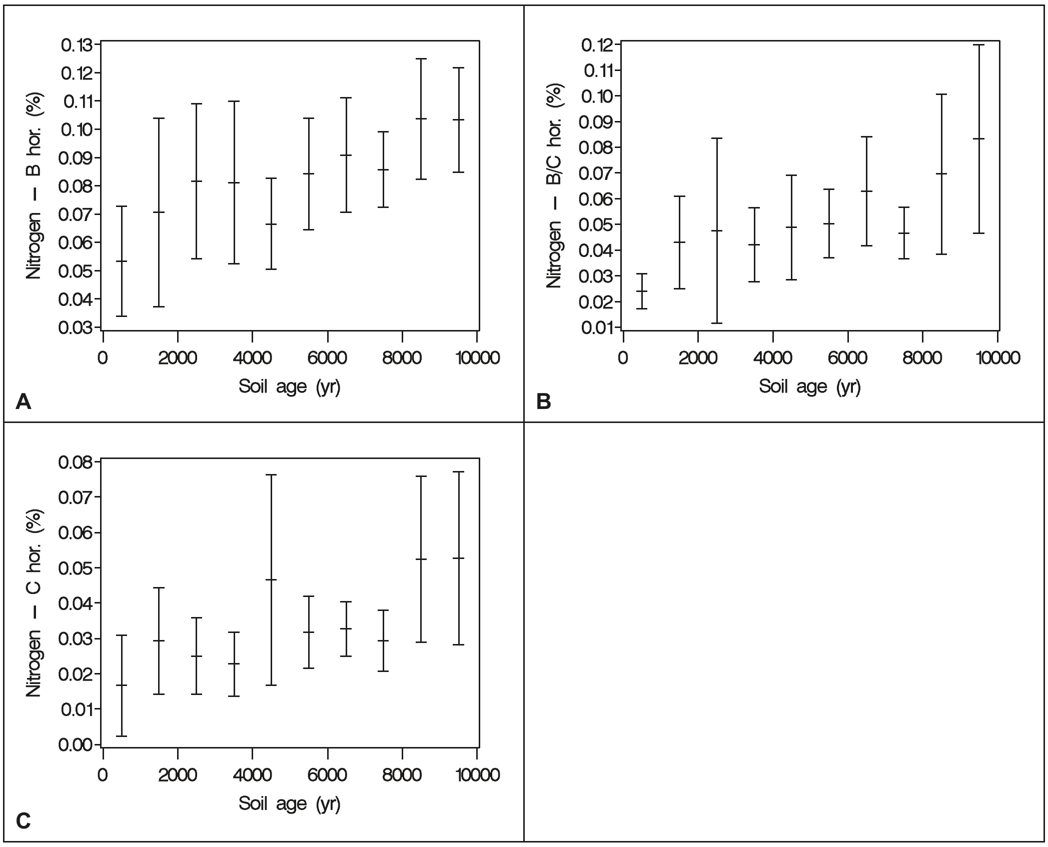

Figure 10-9. Soil nitrogen concentration in Podzols versus soil age including 95% confidence intervals. (A) represents the B horizon, (B) the B/C horizon, and (C) the C horizon.

10.3 Postglacial changes in faunal composition

The climate variations have also affected the faunal composition. There are several early findings of mammal species such as reindeer and mammoth, which lived in southern Sweden shortly after the deglaciation. In the cold but nutrient-rich sea along the Scandinavian west coast, the mammal fauna was characterised by arctic species, e.g. polar bear and a variety of seal and whale species. During the shift to warmer climate at the beginning of Holocene the early mammal species disappeared, and the open landscape in the southern parts of Sweden was dominated by large grazers, e.g. bison, wild horse and aurochs. Certain animal species which today occur further south lived in southern Sweden during the warmest phase of the Holocene (e.g. pond turtle, *Emys orbicularis*). Most of the current mammal fauna was established in southern Sweden during the early Holocene. Some of the early established species, such as aurochs and bison, are now extinct in Sweden, however /Berglund et al. 1996b/.

10.4 Ecosystems, succession and human land use

Succession is a directional change of ecosystem structure and functioning, which may occur over time scales from decades to millennia. Succession may be a result of new land emerging (primary succession) or of disturbance such as after a clear-cut (secondary succession). The vegetation development and the species community through time are constrained by the availability of dispersal propagules and local abiotic conditions /i.e. Rydin and Borgegård 1991, Löfgren and Jerling 2002/. In the investigated coastal areas, the overall regressive shoreline displacement transforms the near-shore sea bottom to new terrestrial areas or to freshwater lakes. The subsequent development of these terrestrial areas and lakes may follow different trajectories depending on factors such as fetch during the marine shore stage, slope and surrounding topography. A schematic illustration of some of the main trajectories is shown in Figure 10-10, where the sea bottom is the starting point and the end point is an inland bog or a forest locality.

The starting conditions for ecosystem succession from the original sea bottom in a coastal area are strongly dependent on the topographical conditions. Deep bottoms accumulate sediments (accumulation bottoms) at a higher rate than shallow bottoms (transport bottoms). During regressive shoreline displacement, a sea bay may either be isolated from the sea at an early stage and thereafter gradually turned into a lake as the water becomes fresh, or it may remain a bay until it is uplifted by shoreline displacement and becomes a wetland or a forest. The Baltic Sea shore can be divided into four main shore types: rocky shores, shores with more or less wave-washed till, sandy shores and shores with fine sediments. Wave-exposed shores will be subject to a relocation of earlier allocated sediments and these shores will emerge as wave-washed till. The grain size of the remaining sediments will therefore be a function of the fetch or wave exposure at the specific shore /Sohlenius and Hedenström 2008/.

In coastal basins that will later develop into lakes, there is a threshold in the mouth of the basin towards the open sea. This threshold allows settling fine material to accumulate in the deeper parts of the basin. Provided that the water depth is less than 2–3 m, different macrophyte species (e.g. *Chara* sp.) colonize the illuminated sediments. Along the shores, *Phragmites* and other aquatic vascular plants colonize the system, and a wind-sheltered littoral zone is developed. In both of these habitats, colonization by plants reduces the water currents, resulting in increased sedimentation and accelerated terrestrialization of the bay. When the threshold is lifted above the sea level, inflow of fresh surface water and groundwater slowly changes the system from a brackish to a freshwater stage. The long-term fate of all lakes is inevitable infilling and transformation to either a wetland or a drier land area, the final result depending on local hydrological and climatic conditions.

Almost all vegetation types in southern Sweden have been strongly influenced by human activities in the past as well as the present. This influence has varied over time depending on the size of human population. Some vegetation types, such as agricultural land, are man-made, whereas other types are kept at a successional stage otherwise found during a restricted period following shoreline displacement, e.g. a meadow. The following sections describe the formation and development of three major vegetation types: wetlands, agriculture land and forests. Each vegetation type description is followed by a description of historical land use in general and more specifically for the both sites.

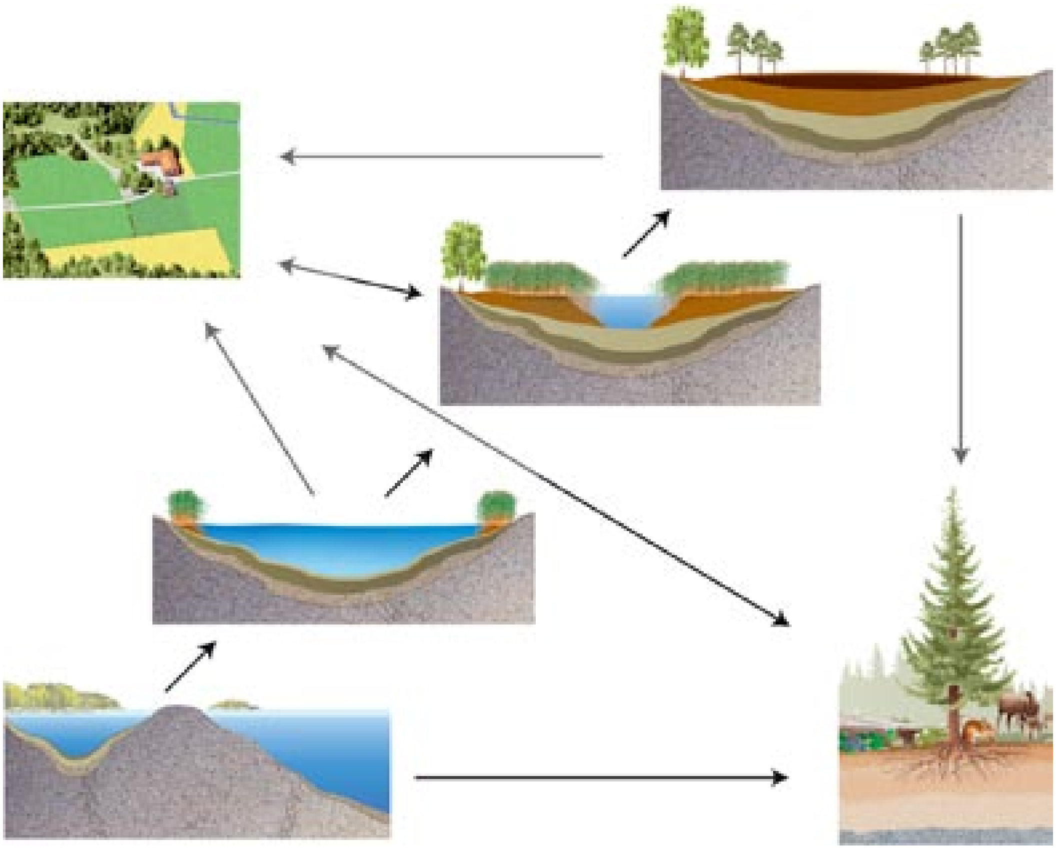

Figure 10-10. *A schematic illustration of the major ecosystems that may be found at certain points during a temporal sequence, where the original sea bottom slowly becomes land due to shoreline displacement. Black arrows indicate natural succession, while grey arrows indicate human-induced changes to provide new agricultural land or improved forestry. Agricultural land may be abandoned and will then develop into forest or, if the hydrological conditions are suitable, into a fen. A forest may be "slashed and burned" and used as agriculture land. From /Söderbäck (ed.) 2008/.*

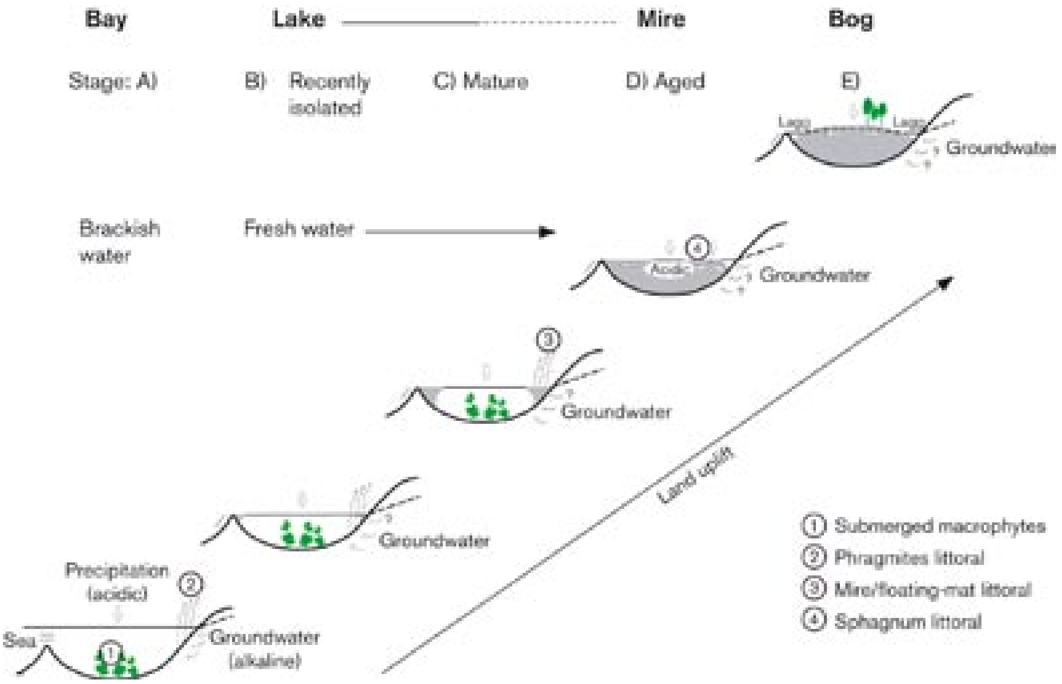

Figure 10-11. *Schematic description of the ontogeny of a closed-off bay of the sea to a mire. The figures represent different important components of the ecosystem. Modified from /Brunberg and Blomqvist 2000/.*

10.4.1 Wetland

Wetland succession has been debated in the scientific literature /Mitsch and Gosselink 2000/. Wetlands are often described as ecotones, that is, transitional spatial gradients between adjacent aquatic and terrestrial environments. Thus, wetlands can be considered transitional in both space and time. As ecotones, wetlands usually interact strongly with varying external forces from both ends of the ecotone. These forces may drive a wetland towards its terrestrial neighbour if, for example, water levels drop or toward its aquatic neighbour if water levels rise. Alternatively, plant production of organic matter may raise the level of the wetland, resulting in a drier environment favouring other kinds of species. Fluctuating hydrologic conditions are the major factor controlling the vegetation pattern /Niering 1989/.

Coastal areas in Sweden are exposed to post-glacial shoreline regression to such an extent that it isolates sea bays, giving rise to new lakes. At a later stage, a shallow lake gradually fills up as organic material decomposes and accumulates. This, together with land uplift, may transform the lake into a mire (see earlier chapter, Figure 10-11). The most common succession for a shallow lake is that it becomes a reed marsh, a fen, possibly with a stage of swamp, and eventually a bog (Figure 10-12), which is the most common endpoint /Walker 1970/. In anoxic sediment, peat starts to accumulate. As the land rises, the fen becomes more and more elevated and at some stage it starts to leach out nutrients /Jonsell and Jonsell 1995/. The fen nutrient content decreases, which promotes *Sphagnum* mosses which can create large carpets of peat that retain water. Finally, the fen turns into a bog as nutrient levels and pH decrease in the wetland.

There are three principal ways for a mire to be developed /Kellner 2003/:

1. Primary mire formation. This is when the fresh soil surface is directly occupied by mire vegetation after emergence from water or ice. Primary peat production will occur at the sites that are wet during sufficiently long parts of the growing season to promote mire vegetation. At the same time as the peat grows (in height), it will most likely also expand laterally, either by lake filling (terrestrialization) or by paludification, see below. This type of mire formation is common along the coast of Uppland and in northern Sweden.
2. Terrestrialization. This constitutes a hydroseral succession from an open water basin into a mire /von Post and Granlund 1926, Korhola and Tolonen 1996/. Two formation pathways are described by /Mitsch and Gosselink 2000/: the first is terrestrialization by infilling in a lake basin, or quaking peatland succession, where mosses together with floating or half rooted vegetation cover produce a peat mass that gradually develops from the edges towards the middle of the lake. The peat growth from the borders facilitates a colonization of first shrubs and then trees, forming rings towards the centre. After some peat growth it becomes thick enough to isolate the surface from groundwater influence. Some parts then become more nutrient-poor and finally turn into a raised bog. The other process described by /Mitsch and Gosselink, 2000/ is detritus sedimentation on the lake bottom, whereby enough material is built up for marsh vegetation to grow, which continues the build-up of peat, permitting a transition into a fen and later a bog.
3. Paludification. This is the conversion of a mineral soil ecosystem into a mire ecosystem. The terrestrial ecosystems are overgrown by mire-forming vegetation. This process can be brought about by climate changes, geomorphological changes, beaver ponds, forest logging, but more often by a natural advancement of peatlands. The low permeability of adjacent peat layers contributes to a rise of the groundwater table, supporting the lateral expansion of mire vegetation. Paludification is considered to be the predominant cause of mire formation in the wetter parts of Sweden /Rydin et al. 1999/.

All three types of processes are likely to have occurred or to be occurring in the Forsmark and Laxemar-Simpevarp areas, but peatland infilling in lakes (terrestrialization) /von Post and Granlund 1926/ is probably the most common type of peatland development in the areas around the investigated sites. The richer types of mires will undergo natural long-term acidification while turning into a more bog-like mire. It seems that the end result of mire development, in the boreonemoral and southern boreal areas of Sweden is the bog /Rydin et al. 1999/. The bog can, however, have Scots pines if the peat can support their weight and some studies (e.g. /Gunnarsson et al. 2002/ and references therein) indicate that Scots pine have become established and increasingly common on bogs in recent years.

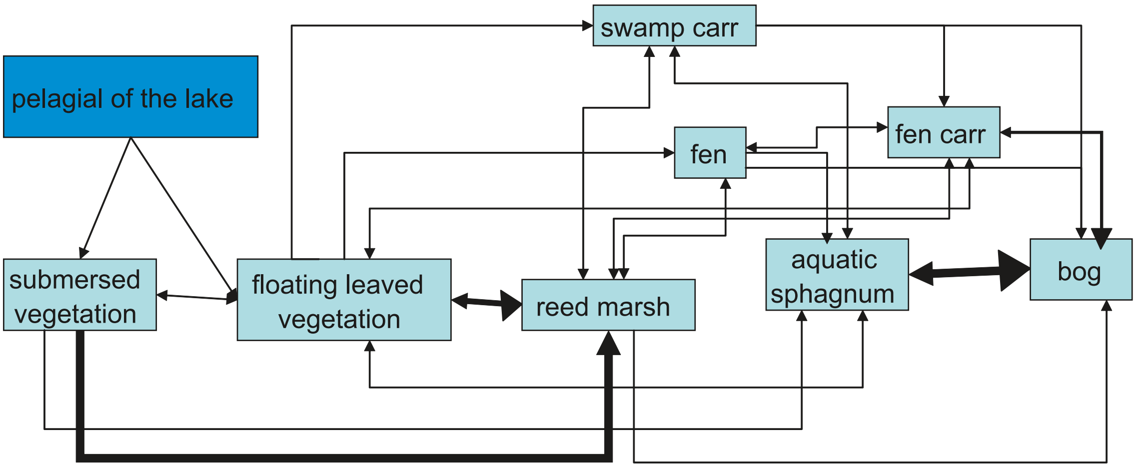

***Figure 10-12.** Wetland succession pathways from lake, through marsh and fen, to bog. Bold lines and arrows show the most common pathways. After /Walker 1970/.*

Land use

Historically, wetland areas were often seen as unfit for use as agricultural or forestry land because of their high water content. They also bred mosquitoes and diseases and were therefore referred to as "festering swamps", "mosquito hells", and "water sick areas". Nevertheless, mires were frequently used for haymaking, and rich fens were more important than poor fens in this respect. Haymaking slows down or stops the succession of a rich fen, resulting in poorer fen-like stages due to the inhibition of peat formation /Elveland 1978/. In Sweden, from the end of the 19th century until the middle of the 20th century, wetlands were not considered a good choice for agriculture. Little was then known of the fact that drainage led to large quantities of accumulated matter that resulted in lowering of the water table, causing a switch from anaerobic conditions to aerobic conditions and initiating decomposition and erosion of peat-dominated soil. Subsequently, great efforts were made to dry out wetlands by draining, digging ditches and lowering lake levels in order to use the land for agriculture and forest industry and to feed the growing population. Such activities peaked in the 1930s /Eliasson 1992/. As much as 90% of the wetlands have been drained in some areas in southern Sweden /Svanberg and Vilborg 2001/.

In Finland, a cultivation method for peatlands was created that consisted of several steps /Myllys 1996/. First the mire was drained, and then the dry mire surface area was burned. Manure and sometimes mineral soil was mixed with the ash layer, resulting in higher crop yields. After some years the area was burned again to restore its fertility. This method of burning destroyed the peat and valuable nutrients were actually lost, especially from nitrogen-rich fens. The quality of the peat used for agriculture varied depending on what sort of peat it was. Moderately decomposed Carex peat was classified as the best peat soil, while undecomposed *Sphagnum* peat soils were considered the worst. However, with new technical methods, liming practices and fertilizers, these old classifications became less important.

Peat cutting has a long tradition in Sweden. Peat was often used as soil improvement material, as bedding in animal barns, and during difficult times for heating /Svanberg and Vilborg 2001/. Peat cutting for energy production in Sweden ended in the 1960s, but was started again in the 1980s.

The Forsmark area

Land suitable for cultivation is situated in the low-lying parts of the terrain and often occurs in small irregular pockets in the surrounding boulder-rich terrain. This meant that the arable fields were, in many cases, small with irregular geometric forms. It is only in the area around the central part of Valö and in the area in the immediate proximity of the Forsmark ironworks that we find larger open areas dominated by arable land (map Appendix I). To increase the amount of fodder, small farms and individual families carried out haymaking with the reeds and grasses on wetland areas. These areas were often distant and hard to reach and were mainly used by poor families that needed to feed their animals. Until the middle of the 19th century there were large wetland areas in the woodlands. These areas were subsequently drained and then cultivated as arable land. Some of these areas are still cultivated while others are now deserted and, in some cases, have become woodlands.

As an example of drainage of wetlands to gain agricultural land, Table 10-1 shows a decrease in wetland areas in Valö in the Forsmark area and an increase in arable land and meadows between the years 1709 and 1829 /Berg et al. 2006/.

The Laxemar-Simpevarp area

The agrarian revolution and the changes that took place during the 19th century also affected the farms and people in the Laxemar-Simpevarp area. New roads were built and new ownership structures became apparent in the landscape. New stone walls were built in straight lines and divided the landscape into separate domains. The meadows were to some degree abandoned and wetlands were reclaimed as arable land in many areas of the region. Landscape change was dramatic during the period encompassed in the study by /Berg et al. 2006/, i.e. between 1940 and 1980. About 74 million square metres of arable land were abandoned between 1940 and 1980. According to the calculations, only 3.8 million new square metres were ploughed in 1980. Of the original 114 million square metres of arable land in 1940, only 41 million were still in production in 1980.

The areal extent of arable land, and even more so of meadows, increased throughout the 18th and 19th centuries. The wetlands in the wooded areas were then also being used as meadows. At the same time, the old meadows located near human settlements were transformed into arable land. The increase in population and the increasing number of farms during the period may partly explain this situation. Another possible explanation is that fishing and fishing-related incomes declined in relation to other incomes and that agriculture increased in importance as a source of income at the same time.

One of the obvious changes that can be observed on maps spanning the period from 1689 to 1872 /e.g. Söderbäck (ed.) 2008/ is an increase in meadows located in the central part of the village. In the 17th century, meadows were concentrated in the eastern part, close to the settlement. Most of the meadows were in the same fenced-in area as the arable land. The picture has changed dramatically one hundred years later, and many of the former wetlands and peatlands were now being used as meadows. This can be interpreted as a result of the increase in population and hence a greater pressure on the landscape, but also probably a change in production with larger livestock requiring winter fodder /Berg et al. 2006/.

Table 10-1. The areal extent of arable land in the mapped areas in Valö in square metres. Observe that the areas differ somewhat over time. The older map from 1709 covers a larger area. It is clear, however, that the extent of arable land and meadows has increased and the wetland area has decreased.

	1709	1829
Arable land	890,597 (2.15%)	1,400,276 (4.75%)
Meadow	5,919,645 (14.30%)	8,031,235 (27.23%)
Wetlands	5,232,176 (12.64%)	990,382 (3.36%)
Water	1,651,885 (3.99%)	51,335 (0.17%)
Total	41,387,890 (100.00%)	29,489,330 (100.00%)

10.4.2 Agricultural land

The distribution of agricultural land in Sweden today is largely associated with postglacial deposits /Angelstam 1992, Sporrong et al. 1995/. The agricultural land in Laxemar-Simpevarp today is characterized by having clay-silt as the dominant QD in the surface layer, closely followed by clayey gyttja (and gyttja clay). However, the clay-silt category includes both clay gyttja and gyttja clay as well as clay because of differences in classification for parts of the area.

The largest arable land unit in the Forsmark area is found on clayey till. Gyttja as the dominant soil on agriculture land is scarce in this area, which suggests that present-day agricultural areas are seldom preceded by an extended lake phase with organic sediment deposition. A part of the agriculture land has a dominant peat layer, which is built up during the phase as a wetland. Due to different mapping techniques, the peat classification into different types has not been uniform on all the sites. In areas where detailed mapping has been performed, more nutrient-rich fen and nutrient-poor bog peat were distinguished /Rudmark et al. 2005/. In these areas, all agricultural areas were located on fen peat. In the western area, peat was mapped as unclassified peat. However, fen peat is probably dominant in this area as well. One category having clay gyttja (and gyttja clay) with a thin layer of peat suggests a somewhat faster succession where the wetland stage was rather short or that the peat has oxidized during a long period of cultivation. Another category of agriculture land with regard to QD is characterized by more coarse grained non-organic materials that were deposited during the sea phase, such as wave-washed sand, gravel and till.

Land use

Before the modernisation of agriculture, only fairly dry soils could be cultivated. Heavy clays and wetlands were used for mowing, and stone-ridden tills and bedrock were grazed. In Nynäs in Södermanland, it was found that thin soils on bedrock were used for cultivation close to the villages in the 17th and 18th centuries /Cousins 2001/. As management intensity and population increased, more of the medium-fertile soils were used for agriculture, while the poorest soils were set aside for grazing /Rosén and Borgegård 1999/. However, this trend came to an end as management was rationalized by the use of fertilisers and better equipment in the early 20th century. This development of farming and the development of forest tools and machinery altered the land use and its association with different soils. Sweden has experienced a nation-wide regression in agricultural activities, and if former farmland areas are left unattended, they will eventually become forests that in most cases will be dominated by Norway spruce. During the late 1900s, farmers have been encouraged to plant coniferous trees on arable land, thereby accelerating the succession into forest.

The Forsmark area

In the early 18th century, there were a large number of crofters in the forest situated to the north of the Forsmark ironworks. A map from 1734 shows that there were 19 crofters spread throughout this area. The crofters had small areas of arable land and meadows were situated close to their houses. These crofts were probably established during the 17th century as a consequence of the labour demand from the ironworks. The crofts were located in the woodlands, often in small valleys with fertile soil. By the beginning of 20th century, the number of crofters had increased to 120. The crofts represent a new wave of colonization in the area, which took place from the 17th century onwards. The crofts also represent the physical manifestation of the labour requirements of the Forsmark ironworks. At the beginning of the 20th century, the area was quite densely settled (Figure 10-13). Many of these crofters' places are still used today, but not for agriculture. Instead, they are used as summer houses or as permanent residences.

In the Forsmark region, most of the arable land remained unchanged between the early 1900s and the 1950s. The land use in the Forsmark region in the late 19th century can be seen in the detailed map of hundreds (*Sw. häradskartan*). From these maps it is possible to discern arable land, meadows, settlements and other information (Figure 10-13) /Berg et al. 2006/. Some of the arable land,

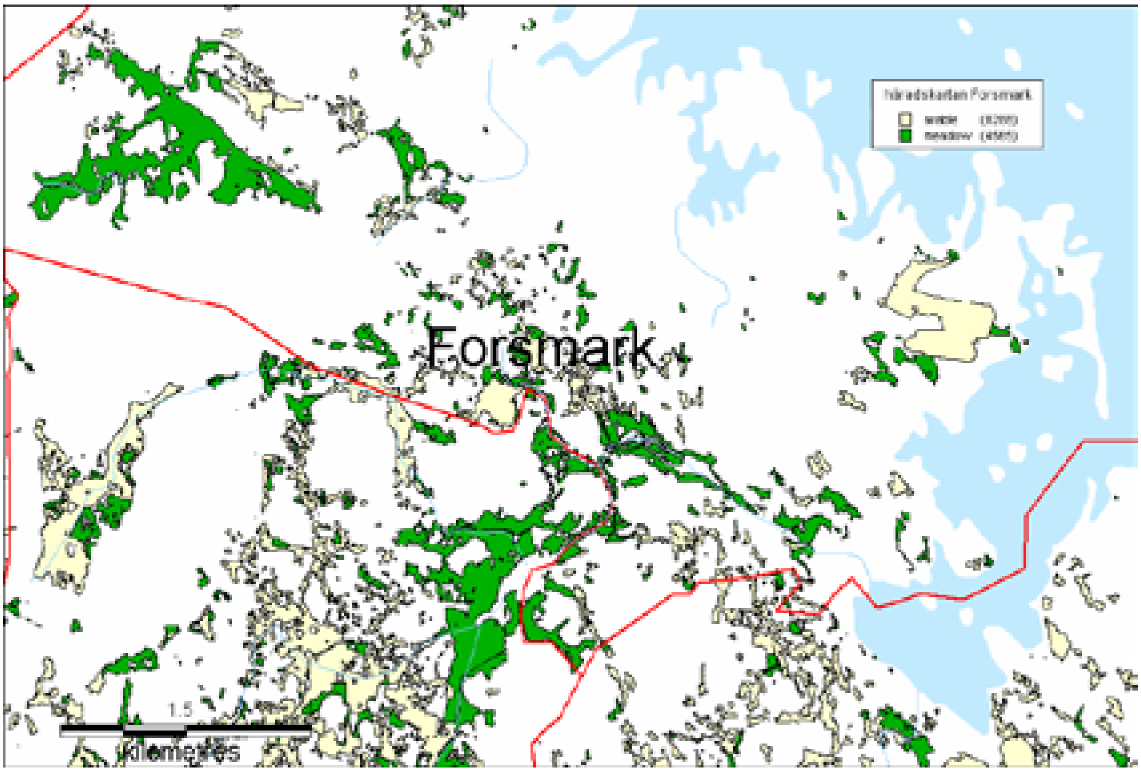

Figure 10-13. *Extent of arable land and meadows from the map of hundreds (Sw. häradskartan), 1905. In the Forsmark area, large areas of meadow covered the lower elevated parts of the landscape. From /Berg et al. 2006/.*

comprising about 26 million square metres (equivalent to c 18% of the total amount of arable land), was abandoned during the period. However, during the same period almost 65 million new square metres of arable land was created in other places in the region. The total amount of arable land in the Forsmark region in 1950 was 148 million square metres /Berg et al. 2006/.

Many of the large estates abandoned agriculture during the 20th century and the land was leased out. The decrease in the number of farms has also brought many changes to the region. Many of the farms belonging both to the old nobility and to the freeholders were converted to dwelling houses of different types. The large areas of forest that were needed for the production of charcoal were in many cases purchased by large timber companies. The surviving farms often bought arable lands in order to merge into larger holdings. Another possibility was to lease land from the land owners not involved in farming. To some extent, this arable land was then used solely for the production of silage and fodder, and not as arable land.

Two elderly farmers in the area were interviewed, and they pointed out many small fields on the map that were harvested in the old days but are today are overgrown with shrubs and trees. It can be concluded that there have also been local transitions where many smaller fields (which the elderly farmers remember as having been cultivated in the past) have been abandoned, become overgrown and closed /Berg et al. 2006/.

The Laxemar-Simpevarp area

Detailed historical maps of the investigated region indicate that most farms were in fact small, and that the arable fields principally consisted of patches of land, which were often filled with clearance cairns. In the early maps from the 17th and 18th centuries, many meadows can be observed. The meadows were often located next to the cultivated fields. Small wooded areas or single trees could grow in the meadow without preventing the production of winter fodder. The leaves and twigs from the trees were used as fodder for smaller animals such as goats or sheep /Berg et al. 2006/. Before the 17th century, large parts of the region were owned by the crown, but during the 19th century this changed. When the nobles took over, several industrial investments were made. The nobles brought new inventions to the region during the 19th and 20th centuries. Bogs and wet-meadows became arable land through ditching, and stone fences were built to protect the forest from the livestock /Lundqvist 2006/. Landscape transformation in the Laxemar-Simpevarp region was dramatic in the middle of the 20th century. Of the 114 million square metres of arable land in 1940, only 41 million were still in production in 1980, i.e. approximately 36% of the former arable land. Only 3.8 million square metres of new arable land were ploughed in 1980. The forms of the arable fields can also be analyzed in relation to the changes. It is common that field configurations have become simplified over time, i.e. that the irregular shapes and forms have been changed into simple rectangular forms /Berg et al. 2006/ to make cultivation more efficient.

Another important characteristic of the region is the location of farms on the coast or in the archipelago. These farms, such as the ones on Ävrö, show that arable production was not always the most important form of livelihood for the farm economy. The location of such settlements, sometime relatively far away from arable land, was closely connected to the importance of fishing /Berg et al. 2006/. The households in the archipelago had strong traditions and a high degree of self-sufficiency, where fishing and livestock-raising constituted the main occupations. The many islands in the region provided excellent pastures for the livestock. Cultivated products such as cereal were exchanged with farmers from the mainland. During the 18th and 19th centuries, the number of households increased drastically in the region and the reclamation of land was intense /Lundqvist 2006/. People practised livestock-raising, which was so intense that many areas in the archipelago were overgrazed. There was no agriculture worth mentioning in the archipelago before the middle of the 18th century, when it became more frequent. Agriculture was always limited, though, due to the lack of suitable land /Lundqvist 2006/.

The extent of arable and especially meadow land increased during the 18th and the 19th centuries. During the early phase, most of the intensively used lands were located close to settlements, but this subsequently changed and many parts of the landscape were brought into agricultural production. Crofts also emerged in most hamlets, but they were not particularly numerous. At the time of the land reforms in the 19th century, some farms were moved from their original locations and relocated to the areas with "new" arable lands. This often affected the crofts, which sometimes had to be moved even further away from the old hamlets to agriculturally less advantageous locations. During the 20th century, the extent of arable land began to decrease. The changes were most pronounced in the latter half of the century. This coincides with the introduction of tractors, modern machinery and the adjustment in the size of a viable farm. Following the Second World War, the number of farms decreased, and in many small hamlets in the region there was only one or no active farm left. To some extent this has lead to the merging of farms, but the general trend is that most old farms remain as property even though farming is no longer carried out by the present owners. This has led to a complex system of leaseholds, where one farm can lease many farms or parts of former farms – a system still in use today. The need for large areas of arable land and the small sizes of the farms also increases the number of leaseholds needed for a farm to survive. The specialization of agriculture has also made it more efficient. Some farmers have focused on milk production while others focus on meat, cereal production, etc. This has had the effect that many arable fields are nowadays only used for fodder or for silage production. Before this change, fodder production was incorporated into a system of rotation between crops and fodder. Several lakes were also lowered during the early to mid 20th century, e.g. the former Lake Gästern. Certain of the areas used as arable land have consequently been drained quite recently /Sohlenius and Hedenström 2008/.

Concluding comments

The main differences in land use history between the sites were summarized by /Berg et al. 2006/ as follows: Firstly, a difference in traditional land use can be recognized between the sites. It seems that there has been more diverse land use in the Laxemar-Simpevarp area, focusing more on fishing, hunting and berry-picking. In the Forsmark area, however, land use has been more focused on the traditional practice of growing crops. Secondly, the reorganization of farms has been carried one step further towards obtaining farms of sufficient size in the Forsmark area than in the Laxemar-Simpevarp area. In the Laxemar-Simpevarp area, most farms are still intact from the time of the land reforms, and the current land users are instead leasing many tracts of land from other farms, with up to 25 leases in some cases. In the Forsmark area, large forest companies bought whole farms in the post-war period and sold off the arable land to family farmers. In the Laxemar-Simpevarp area, most farms are still owned by the same families as in the early twenties. Thirdly, the spatial dimensions are different in terms of field size and distribution. Today it is necessary to have somewhere in the region of 50 to 60 cows to have a solid economic base for milk production. In the Laxemar-Simpevarp area, however, there is not enough grassland close to the hamlets and not enough fodder-producing areas in the proximity of farms to make it economically sustainable. According to those who were interviewed, this makes the establishment of a dairy farm in the region increasingly difficult. In the Forsmark area, however, it is still possible to keep that number of cows, which has resulted in modernization and investments in milking machines and new stables.

/Berg et al. 2006/ summarized the two case studies as follows: it can be said that land use in both areas regarded on a large scale is agriculturally marginal. In both areas, land use is to some extent dependant on subsidies. On the other hand, in the Laxemar-Simpevarp area many landowners do not see much of a future for farming, whereas in the Forsmark area the idea of farming as a source of revenue and a livelihood is still alive. This is an example of a subtle psychological factor that will probably have effects on how land will be used in the future /Berg et al. 2006/.

10.4.3 Forest

Land uplift continuously creates new terrestrial areas. The most important abiotic conditions affecting the vegetation community on the sea shore are soil type, degree of exposure and salinity /Jerling 1999/. Soil type is strongly related to the degree of exposure, where more wave-exposed areas contain larger stone fractions than areas with low exposure. Studies of the vegetation on the Baltic Sea shores show that emerging areas are rapidly colonized by vegetation /Ericson and Wallentinus 1979/. Due to the flooding frequency and salt spray intensity, vegetation composition does not change independently of the land uplift rate until many years after the emergence of sites from the sea /Cramer 1986/. The Baltic Sea shore can be divided into four different types: rocky shores, shores with wave-washed till, sandy shores and shores with fine sediments. In the Laxemar-Simpevarp area, rocky shores are the most common, followed by shores with wave-washed till; shores with fine sediments also occur. The emerging rocky and till shores have a sea shore vegetation zonation that is defined by their tolerance to water inundation and salt sprays /Jerling 1999, Jerling et al. 2001/. The first pioneer woody species are blackthorn (*Prunus spinosa*) and alder. Both these species have a litter that is rich in nitrogen, and this facilitates the establishment of many species. Bushes and trees create a varied light environment and new habitats. In this way, the flora and vegetation change steadily but with a relatively high degree of determinism e.g. /Svensson and Jeglum 2000/. In most areas with a thicker soil layer, Norway spruce forest has to be regarded as the climax vegetation type in this area. Scots pine would probably be more restricted to areas with a shallower, more nutrient poor soil layer if forestry management were to decrease and fire were once again to become a natural disturbance in the landscape /Sjörs 1967, Engelmark and Hytteborn 1999/.

The most important structuring factor in the northern boreal forests has been the occurrence of different fire intervals. The fire interval is shorter in areas with shallower soil, and more fire-tolerant pine therefore dominates less productive soil and the forests. More productive and mesic sites are characterized by longer fire intervals and dominated by spruce. Other important disturbances may be insect outbreaks, windstorms and clear-cuts. The spatial scale of these disturbances determines whether they may promote recruitment of new even-aged cohorts or multi-aged stand structures. On less fire-prone soils, a more small-scale gap dynamic, due to the falling of a single or several trees, is important for regeneration. Fire has also been an important factor in the south of Sweden, as forests were often used for shifting agriculture, were areas were logged, burnt and then used for sowing crops. These small fields were then abandoned due to a steady decrease in productivity. Later on there was a general trend until the early 20th that farmland expanded into forested areas. However, as in other developed countries, former agriculture land is often brought back to forest as agriculture production becomes more efficient /Angelstam 1992/. Today, fire has lost its importance in many regions due to efficient fire suppression.

Land use

During the first phase of the Younger Stone Age, the dense forests were cleared, often by the use of fire, and the open areas created were first cultivated for some years and then used as grazing land. When the available soil nutrients were depleted, the area was abandoned and became overgrown. After 30–40 years it was possible to clear and use the area again. The extensive farming, in combination with a growing population, means that large areas were utilized. Within c 1,000 years, human land use had brought about large changes of the landscape in southern Sweden. /Söderbäck (ed.) 2008/.

Tar and lumber also became commercially important. It is difficult to evaluate the relative importance of natural factors affecting the conifer forests. However, the lack of management is important for the species richness in the boreal forests /Esseen et al. 1992/. In the past there were no sharp borders between forest and agricultural land, as forest were grazed and areas were mowed or cultivated in non-permanent fields. Extensive grazing of livestock in the forests is believed to have been an important factor affecting the plant communities around villages in the more densely populated parts of Sweden. Effects of forest grazing may still be a factor in plant community change in forests today, although this has so far not been well documented.

The Forsmark area

Mining iron has had an important role in the region since the Iron Age /Mattson and Stridberg 1980/. As the iron industry became more organized in the 16th century, forests were cut down to feed furnaces and mines with wood and charcoal. The region around the Lake Mälaren was almost depleted of trees at the end of this period /Welinder et al. 1998/. The settlement situation in the Forsmark area in the early-modern period was heavily dependent on the establishment of the *Forsmarks bruk* ironworks. In the 17th century, a large number of ironworks were established around Dannemora. Most of these are known as *Vallonbruk* due to the fact that people from southern and south-eastern Belgium, i.e. Walloons, established them or ran them during the 17th and 18th centuries. A prerequisite for iron production was a large and reliable supply of charcoal (Figure 10-14). The forest was therefore the single most important resource in the Forsmark region due to charcoal production, but the wood was also needed for building material and for fuel. *Lövsta* ironworks was permitted to forge c 1,105 tonnes of bar iron that required c 20,000 m^3 of charcoal. Producing this amount of charcoal required an estimated 30,000 days of work /Renting 1996/. Most of the charcoal had to be produced close to the production site /Karlsson 1990/. These figures indicate that the supply of charcoal was as crucial as the ore for production to be able to function on a regular basis. To ensure preservation of the forests and maintain production, forestry in the modern sense was introduced relatively early in these areas. Since iron was an important product for the country, the crown tried to restrict the use of the forests by spatially separating the mines, the blast furnaces and the forges from one another, i.e. certain areas were dedicated solely to one of these activities /Kardell 2003/.

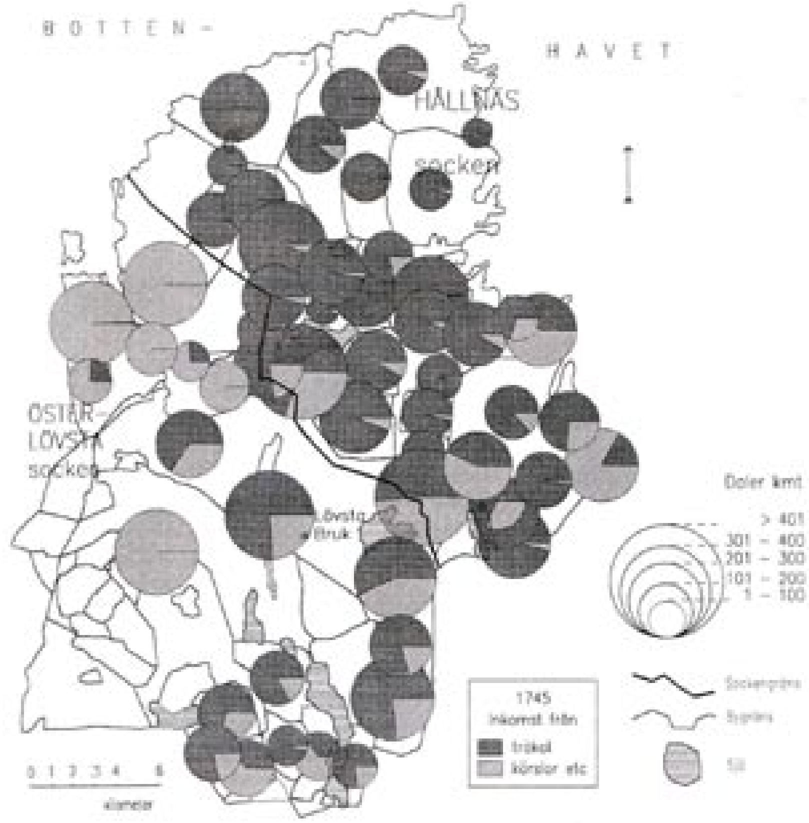

Figure 10-14. One of the important sources of income for farmers was charcoal, but transportation of ore and finished products was also important for the local economy. This map shows the relative importance of the two types of income in the region around Lövsta bruk in 1745 /Renting 1996 p. 131/. /From Berg et al. 2006/.

In the 1950s and 1960s, a number of large estates abandoned farming and focused on forestry instead. This transition can be attributed to the large increases in the costs of employing people to cultivate and run large farms /Flygare and Isacson 2003/. These large estates were converted to or sold out to large forest companies, who retained the forests but often sold off the arable land to smaller family farmers. All present-day farms in the area are former family farms /Berg et al. 2006/.

The current landscape cannot be fully understood without understanding the effects of the iron industry and the landowners. The landscape in the archipelago and the surrounding areas should also be viewed in the context of the fact that the mines, the blast furnaces, and the forges were central places of employment in the region /Berg et al. 2006/.

The Laxemar-Simpevarp area

The forests in the Laxemar-Simpevarp area were used for many different purposes, such as pastures, firewood, fencing material, subsistence needs, slash-and-burn (Sw. *svedjebruk*), as well as production of charcoal, tar and potash. In addition to sawmill activities, production of charcoal, tar and potash was in many cases an important part of the household economy. Trading with timber was advantageous since the timber was easily transported in the coastal areas. In the Laxemar-Simpevarp region, there was also a boat-building tradition that grew into a minor shipbuilding industry during the 19th century /Lundqvist 2006/.

From the early-modern period onwards, the large forested areas, which were jointly owned by many farms and small hamlets, were divided between the different land-owners. This is an important change in the management of forests. The creation of different holdings with clear boundaries created the type of forestry that we are used to seeing today, a forest with often similar vegetational characteristics within rectangular demarcated areas (Figure 10-15). We can observe a partitioning of the farms from the 17th century onwards. This further changed the land ownership structure in that land holdings became smaller.

Concluding comments

Current land use in the Forsmark and Laxemar-Simpevarp areas is in some respects typical of forested rural areas in Sweden: small-scale family based on grazing animals dominates in both areas. However, there are some subtle but important differences. First, a difference in traditional land use can be recognized between the sites. It seems that there has been more diverse land use in the Laxemar-Simpevarp area, focusing more on fishing, hunting and berry-picking. In the Forsmark area, however, land use has been more focused on the traditional practice of growing crops. Secondly, the reorganization of farms has been carried one step further towards obtaining farms of sufficient size in the Forsmark area than in Laxemar-Simpevarp area. In the Laxemar-Simpevarp area most farms are still intact from the time of the land reforms, and the current land users are instead leasing many tracts of land from other farms, with up to 25 leases in some cases. In the Forsmark area, large forest companies bought whole farms in the post-war period and sold off the arable land to family farmers. In the Laxemar-Simpevarp area, most farms are still owned by the same families as in the early twenties.

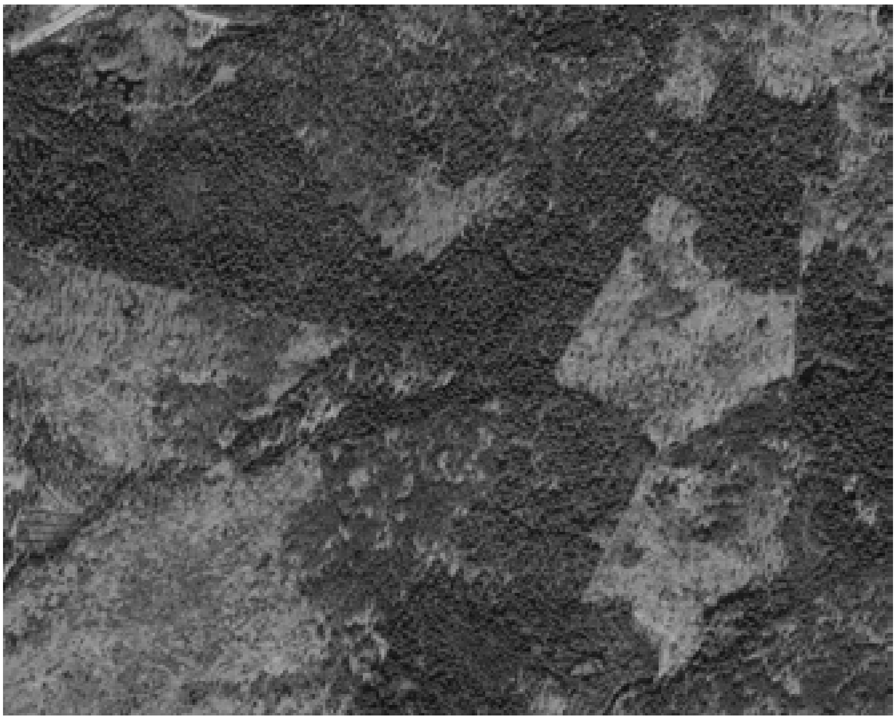

Figure 10-15. *The rectangular pattern in the forests can be observed in many parts of the investigated area. This pattern is often attributed to the new division of the forests that took place as a result of the land reforms during the 17th and 18th centuries. This aerial photograph from 2001 of the forests between Finnshult and Fallegärde, north-west of Oskarshamn, exemplifies this well. /From Berg et al. 2006/.*

11 Concluding and generalizing description of the terrestrial ecosystems in Forsmark and Laxemar-Simpevarp

11.1 Introduction

In this chapter, a number of important features of the terrestrial ecosystem are generalised and discussed for each site. These features are all regarded as important input to the safety analysis to which this work is a basic input. There are three major aims with this report; 1) to characterise and describe the terrestrial ecosystems of today and how these were distributed in the past for the Forsmark and the Laxemar-Simpevarp areas, and, moreover, put the describing data into a larger context of other regions, 2) to describe major pools, fluxes and sinks of elements within the terrestrial ecosystems, and finally 3) to describe the human impact on the terrestrial ecosystems of both areas. These descriptions have been made at a certain level of detail, where information has been used from different sources, such as field investigations, modelling and literature, and these descriptions have been presented in the preceding chapters.

Modelling the fate of long-lived radionuclides released from an underground nuclear waste repository entering the surface ecosystems is partly constrained by the fact that a number of generalizations and simplifications have to be made. In this chapter the attempt is to make generalizations of the terrestrial ecosystems that may underpin assumptions and/or be used directly in the dose modelling in the safety assessment. Reliable descriptions and generalizations of the present-day ecosystems may be more easily made in comparison with the more long-term predictions that have to be made when modelling the fate of radionuclides entering the surface ecosystems. In this perspective, some aspects of long-term variability and uncertainties are discussed. In the last part of this chapter the distribution and transport of elements are further discussed. The knowledge of how natural analogues/isotopes behave in ecosystems may be used to describe constraints to the potential doses to humans and biota.

11.2 Generalization of the terrestrial ecosystems

Generally, there are a number of similarities between the two sites Forsmark and Laxemar-Simpevarp. Both sites are close to the sea and the shoreline displacement has resulted in relatively young terrestrial ecosystems. This is manifested with lower carbon content, the poorly developed soils, in a thin peat layer in wetlands close to the coast, and in that bogs only are found in the inner parts of the investigation areas or further inland. The vegetation is also similar although Forsmark is situated further north with a somewhat different climate, making e.g. the oak a rare species in this area. However, there are factors, e.g. moisture and nutrient content, which may be more important at the local scale than the regional factors for e.g. net primary production (NPP).

The generalization of properties includes a generalization in both space and in time. The spatial extension is restricted to the regional model area (Appendix 1 and 2). The temporal extensions is put to tens of years, where the ambition is to smooth out extreme values and find an appropriate mean for the sites of present-day conditions that is built upon the site investigations. In some cases, long-term estimates have been used, e.g. for accumulation in the soil organic carbon pool, due to a large variation between years and a continued mineralization of older organic material. In other cases, there have been few site data available and the estimate may be from a specific locality. In most cases the reader is directed to the reference that is presented with the property in the tables.

11.2.1 Wetlands

The flat topography in Forsmark has resulted in a large number of shallow wetlands, whereas Laxemar-Simpevarp with a more pronounced topography, have wetlands along larger valleys. In Laxemar-Simpevarp most of these wetlands have been drained and used as agricultural land. Wetlands may be split into a number of subcategories (see Section 4.1), but are here presented as two categories, where the presence of trees is one important difference and the presence of a well-developed bottom layer is another. A number of estimates of properties are presented in Table 11-1. These estimates are built upon data presented in previous sections. The forested wetland representing Forsmark is mainly derived from a locality having peaty mor rather than peat soils, and therefore the SOC is a mean of two localities having peaty moor.

Long-term variability and uncertanities

Wetlands have been heavily exploited during the last centuries, where an increased need for productive land areas has turned wetlands into agricultural land and forests by drainage activities. From the perspective of a safety assessment it is of outmost importance to be able to understand and predict the continuous accumulation of organic material and accompanying elements in wetlands. The organic material is oxidized when the water table is lowered, implicating a net release of other elements bound to the peat. The estimates of long-term accumulation of organic material in wetlands at the sites presented in this report (Section 4.1.1) are in the higher interval of corresponding estimates from literature. Moreover, the long-term accumulation rates are expected to be lower than the short-term or per year calculations, due to a more or less continuous mineralization in the more deep-lying anoxic layers of the wetland e.g. /Malmer and Wallén 2004/.

11.2.2 Agricultural land

The more pronounced topography in Laxemar-Simpevarp has made wetlands along larger valleys more abundant and many of these wetlands have later been drained and used as agricultural land. This also means that partially peaty soils dominate the agricultural land. The agricultural land is therefore more abundant and evenly dispersed along valleys in Laxemar-Simpevarp than in Forsmark, where the main agricultural area is situated on clayey till in the south east. Arable land, pastures and clear cuts dominate the open land. Many pastures were earlier intensively used but are today a part of the abandoned farmland following the nation wide general regression of agricultural activities.

Table 11-1. Generalized ecosystem properties for an open wetland and a forested wetland found in Forsmark and Laxemar–Simpevarp, respectively.

Properties	Forsmark		Laxemar-Simpevarp	
	Rich fen	Forested wetland	Poor fen	Forested wetland
Area (m^2)[a]	10,766	10,766	3,400	3,400
Catchment area (m^2)[a]	102,900	102,900	30,100	30,100
Biomass (gC m^{-2})	2,186±1,102[b]	5,971[c]	1,453±419[b]	6,226[c]
NPP (gC m^{-2} y^{-1})	253±59[b]	429±122[c]	342±102[b]	360±102[c]
SOC (gC m^{-2} to 1 m)	43,280[d]	5,960[d]	15,600[e]	44,200[e]
Peat depth (m)	1.4[f]	-	0.85[g]	0.85[g]
Acc. (gC m^{-2} y^{-1})[h]	38±11	38±11	29± 4	29± 4

a) Median from Appendix 10, Table A7-1. No attempt was made to separate between wetland categories.
b) Table 4-5, Section 4.1.1.
c) From Table 6-10.
d) Mean from /Lundin et al. 2004/.
e) Mean from Table 6-32 /Sohlenius and Hedenström 2008/.
f) Regolith depth model, Table 5-8 /Hedenström and Sohlenius 2008/.
g) Regolith depth model, Table 6-8 /Sohlenius and Hedenström 2008/.
h) /Sternbeck et al. 2006/.

Table 11-2. Generalized ecosystem properties for an arable land and a grassland found in Forsmark and Laxemar–Simpevarp, respectively. Grain is produced on arable land whereas pastures include both former arable land and seminatural grassland.

Properties	Forsmark		Laxemar-Simpevarp	
	Arable land	Pasture	Arable land	Pasture
Area (m^2)[a]	4,516	4,516	4,900	4,900
Catchment area (m^2)[a]	21,900	21,900	56,000	56,000
Biomass (gC m^{-2})	206±5[b]	383±86[c]	23±11[b]	445±157[c]
NPP (gC m^{-2} y^{-1})	206±5[b]	380±113[c]	23±11[b]	250±93[c]
SOC[d]	13,884	13,884	20,460	27,600
QD	Clayey till	Till	Clay-gyttja	Till
Soil depth to bedrock (m)	5.8[e]	3.6[e]	5.7[f]	2.1[f]

a) Median Appendix table A7-2. No attempt was made to separate between different agricultural land categories.
b) Table 4-11, above- and below ground. Assuming 19 % of total biomass and NPP is allocated to roots.
c) Table 4-15 and 4-16, above- and below-ground.
d) Table 8-4 and 8-5.
e) Table 5-8 /Hedenström and Sohlenius 2008/.
f) Table 6-10 /Sohlenius and Hedenström 2008/.
d) Table 5-8 /Hedenström and Sohlenius 2008/.
e) Table 6-10 /Sohlenius and Hedenström 2008/.

Long-term variability and uncertanities

This land use class is characterized by being sustained by human land use. The socio-economic situation in combination with the technical development has mainly determined the regional development of agricultural land so far. Since the 1940s the trend has been to aggregate and rationalize the agricultural land use, where less fertile soils have been abandoned in favour of larger more fertile areas. In the different land use scenarios developed in Chapter 8, the largest variation in terms of yield from the agricultural land would be created by changes in how much of the land that is used for crop or fodder production. Although this means that more and more low-fertile soils would be incorporated in the category of agricultural land. This incorporation would be restricted by a number of different factors such as the boulder frequency and/or the soil.

The technical development of machinery, plant breeding, nutrient addition and crop rotation have all increased the yield several-fold during the last century. This development may be expected to go on and especially a future implementation of genetically modified organisms may further increase the potential future yields.

11.2.3 Forests

Both sites are dominated by the coniferous trees Scots pine and Norway spruce, and have a long history of forestry. The forestry management is evident today as a fairly high percentage of younger and older clear-cuts are found in the landscape. Table 11-3 presents data for forests at both sites representing forest on ground with a fairly deep soil depth, excluding Scots pine forest found in areas with shallow or non-existing soil layer.

Long-term development of forests has been modeled using both the COUP model (Table 4-25) and the LPJ-GUESS (Table 11-4). The modeled mean biomasses as an average over a 100 year period, beginning from a clear-cut, are similar, although the NPP estimates by LPJ-GUESS are approximately 140 and 120 gC m^{-2} y^{-1} higher for Forsmark and Laxemar-Simpevarp, respectively.

Table 11-3. Generalized ecosystem properties for a forest located on ground with medium to large soil depth found in Forsmark and Laxemar-Simpevarp, respectively.

Properties Dominant species	Forsmark Needle-leaved trees	Laxemar-Simpevarp Needle-leaved trees
Catchment area (m^2)[a]	200	200
Biomass (gC m^{-2})	9,758[b]	8,821[c]
NPP (gC m^{-2} y^{-1})	603[b]	568[c]
SOC (incl. litter)	8,051[b]	9,015[c]
Soil type	Till	Till
Soil depth to bedrock (m)	3.6[d]	2.1[e]

a) Appendix 7.
b) Table 8-3.
c) Table 8-4.
d) Table 5-8 /Hedenström and Sohlenius 2008/.
e) Table 6-10 /Sohlenius and Hedenström 2008/.

Table 11-4. Mean biomass and net primary production with standard deviation for a forest stand during a 100 year period starting after a clear-cut in Forsmark and Laxemar-Simpevarp, respectively. Results are output from the model LPJ-GUESS, using site data for driving variables. The numbers include both field and tree layer and above and below-ground (From Table 7-7).

Properties	Forsmark	Laxemar-Simpevarp
Biomass (gC m^{-2})	6,767±3,536	6,377±2,945
NPP (gC m^{-2} y^{-1})	478±110	484±94

Long-term variability and uncertanities

Short-term variability in biomass and NPP of forest vegetation is high due to a number of factors, such as age, nutrient availability, moisture, exposure and combinations of these. Model results in Chapter 7 also suggest a large variation. Generally, the variability overshadows many of the regional differences that may be described in most of Sweden. However, differences within vegetation types between more southern located areas in comparisons to more northern locations has been made e.g. /Berggren Kleja et al. 2007/. They found that a decrease in biomass and NPP for the tree layer was compensated by a similar increase in the field layer when going from the south to the north in Sweden.

In models covering longer time scales, it would be important to include parameters of climatic change and its effect on vegetation. Such a modelling attempt was presented in /Kjellström et al. 2009/, where the vegetation was modelled during both a warmer and a colder climate using the dynamic vegetation model LPJ-GUESS /Smith et al. 2001/ (see also the description of the model in Chapter 7). This modelling exercise gave estimates of a number of parameters, such as vegetation type, biomass and NPP. Shifts between vegetation zones, due to a climate change, may have important consequences for cultivation and forestry.

11.2.4 Fauna

There are some differences in the species pools between the sites, mainly due to the more northern location of Forsmark. The most abundant free-living herbivores at both sites are moose and roe deer. When livestock are present they have a higher consumption than other large herbivores, although part of their food generally is imported fodder. At present, the red fox is the largest and most common predator at both sites, altough the Forsmark region also has the lynx, that so far is found only in low abundance. Generally, the density estimates at the two sites are similar. The calculations of total consumption by herbivores suggested that the consumption was somewhat higher in Laxemar-Simpevarp, mainly due to a higher abundance of rodents at the time when the density estimates were done.

Long-term variability and uncertanities

The ungulate population densities are mainly restricted by hunting, predators and severe winter conditions. The importance of these may depend on the species in focus. Today, the moose population is under extensive management and will probably be kept within certain boundaries (5-15 ind·10km^{-2}), due to hunting /Truvé 2007/. The roe deer population is also influenced by hunting, but is also affected by the presence of red fox and lynx that both have increasing populations today. Generally, a lower hunting pressure on both herbivores and predators could initially mean higher ungulate populations, but would also imply increasing and expanding predator populations. These would probably restrict the ungulate populations below population densities found today.

11.2.5 Land use

Without exception human land use has to be regarded the most important factor structuring the landscape. In present-day Europe there are hardly any habitats or landscapes that have not been more or less influenced by human activities /Bakker 1989, Berglund 1991/. People have influenced the landscape in south eastern Sweden more or less intensively since the last Ice Age. A rich diversity of habitats containing large numbers of plant species, including many that probably did not occur in the original natural landscape, has developed as a result of varying natural conditions combined with different land use. Major factors affecting the flora and fauna are clear-cutting, agricultural management, abandonment resulting in a natural succession, and intensified management.

The amount of resources in the area that humans can utilise is described in Section 8.4.3. This information can be distributed over the different ecosystems in order to estimate how much food that can be obtained from each ecosystem for a sustainable population of humans. This will also enable estimations of the maximum sustainable population at the site.

Long-term variability and uncertanities

Physical properties, e.g. soil properties, bedrock type and topography, are important prerequisites for land use. Historical maps reveal a close connection between land use intensity and land-cover distribution. The more fertile soils were used for agricultural purposes while the less fertile soils were used more extensively for grazing. As management intensity and population increased, more of the medium fertile soils were used for agriculture while the poorest soils were assigned to the livestock /Rosén and Borgegård 1999/. Physical properties are important prerequisites for land use but on the other hand, land use can alter biophysical properties both in a short and long time perspective. For example, drainage of soils, straightening of rivers, nutrient depletion, and plantation of conifers or broad-leafed trees may alter the soil properties within a generation.

The identification of how historical and present-day land use is correlated with factors, such as Quaternary deposits and vegetation, makes it possible to predict landscape changes in the future if we know the land use intensity. One approach may be to model four major scenarios: abandonment, intensification due to cultivation, intensification due to forest management and *status quo* of the present-day land use. This would generate a full-scale picture of how the landscape configuration could vary depending on land use intensity and type of management. The input data for this analysis would be retrieved from historical data presented in this report and in /Söderbäck (ed.) 2008/.

11.3 Element pools and fluxes

Elements are transported and accumulated in the biosphere to different extents depending on the properties of the element and on the context it is exposed to. Descriptions of pools and fluxes presented in Chapter 8 and 9 underpin the understanding of accumulation and turnover of elements in different pools in terrestrial ecosystems.

11.3.1 Energy, carbon or organic matter

In the description of fluxes of matter entering the food web, as well as of fluxes within the food web, energy, carbon and organic matter may be regarded as interchangeable quantities. These quantities are also suitable for describing sinks of matter that in a first step is incorporated into biota, and that later is accumulated, more or less decomposed, in the form of e.g. humus or peat in certain parts of the landscape. Many other bioavialable elements follow the same pathway as organic carbon, but accumulation rates may differ between elements, partly due to different mineralization rates. As an example, limiting macro- and micronutrients are generally mineralized at a faster rate than non-limiting elements.

Pools

The field- and model-estimated carbon pools and fluxes for a large number of vegetation types revealed some general pattern common to both sites. The largest carbon pool was found in the humus and mineral soil, followed by the vegetation. Vegetation types with water-logged soils had higher carbon content due the thicker organic horizon or a dominating peat layer. The potential size of the pool may serve as a limit to how much that may be accumulated with regard to other elements that follows carbon in a stoichiometric relationship.

Fluxes

The largest carbon flux is the uptake of carbon by primary producers, where approximately half is transformed into biomass. This net primary production creates a demand of a number of macro- and micronutrients that are incorporated into the biomass according to more or less well-described stoichiometric relationships, e.g. /Sterner and Elser 2002/. The majority of these elements are taken from the soil via the fine roots, e.g. /Greger 2004/. Along with this uptake of necessary elements, a number of other elements are also incorporated into the biomass in small amounts. Consequently, NPP will set the upper limit to the potential incorporation of different elements into biomass. The NPP may vary over time as an effect of changing properties of the vegetation, but also due to differences in climatic variables between years. Long-term estimates, as in Table 10-4, may therefore serve as an approximation for long-term uptake in e.g. forest stands subjected to clear-cutting. Biomass does eventually reach the soil compartment as litter, where it is mineralized. The balance between litter production and heterotrophic respiration determines to what extent organic material (and incorporated elements) may be accumulated in the soil.

Sinks and sources of carbon

The accumulation of carbon was, however, dominated by accumulation in vegetation. The comparative approach revealed that some of the studied ecosystems were more or less reluctant to emit or accumulate organic material. For example, a clear-cut initiates an increased soil respiration and a release of organically bound elements, while some wetland types have a long-term accumulation of organic matter. Especially wetlands dominated by reed in close connection to lakes had both a high production and a high accumulation in the soil organic matter pool.

Both the young soils and the water-logged soils in wetlands are today subjected to a continuous accumulation of carbon. In water-logged soils, the mineralization may be restricted by the anaerobic conditions, whereas in well-drained soils litter production and heterotrophic respiration may be closer to equilibrium. In the more well-drained forests, the organic matter pool in the humus layer seems to build up of over shorter time periods. The humus layer is easily released by fire and seems to vary with the age of the forest /Liski et al. 1998/.

The results in Chapter 10 indicate that the total carbon and nitrogen stocks in Podzol soils reaches equilibrium after approximately 2,500 years, which is similar to the approximately 2,000 years reported by /Liski et al. 1998/. However, in deeper soil layers, the carbon concentration seems to increase for c 6,000 years and then level off, indicating a slower dynamic in soil forming processes in deeper horizons. Except for decomposition of organic matter, soil forming processes result in leaching and enrichment of elements within the soil profile. Eventually, these processes will cause a lower pH and relocalisation of elements within the soils. Probably, this relocalisation will go faster in the Laxemar-Simpevarp area, due to the higher buffering capacity in the lime-enriched Forsmark soils. The water-logged soils are today in most cases described as fens, which are feed with water from a catchment area, and accumulate peaty soil. The organic matter does to a major part originate from autochthonous production within the fen. The water-logged peaty soils may further be subjected to accumulation of elements transported with water (e.g. DOC) that adhere to organic material.

An agricultural land that have a history as a drained peatland will be subjected to a continuous oxidation of peat, where other elements bound to the organic material also will be released when peatland is transformed to agricultural land. A previous sink will suddenly turn into a source not only for carbon but also for elements earlier accumulated in biomass and later accumulated by adhesive forces to the organic matter.

Food web

Calculated fluxes to free-living mammals, livestock, birds, amphibians and reptiles revealed that the largest flux in the food web was found between agricultural land and livestock. The most important herbivore with regard to consumption and production (except for livestock) is in Forsmark roe deer, closely followed by moose, while the opposite is true in Laxemar-Simpevarp. Livestock consumption is the largest flux of carbon from the vegetation, but there is a greater difference between livestock and wild game consumption in Laxemar-Simpevarp than in Forsmark, due to higher abundances of livestock in Laxemar-Simpevarp. In some catchments where livestock was absent, the consumption of vegetation was low. Herbivore consumption (disregarding livestock) is close to 0.5% of the NPP at both sites. Humans were mainly utilizing crops and products from livestock, such as milk, egg and meat.

Output from the terrestrial system

Export of carbon is mainly in the form of dissolved organic carbon. In relation to the internal fluxes of carbon in the terrestrial ecosystems the export is generally low.

11.3.2 Phosphorous, Thorium, Uranium and Iodine

The mass balances of four elements illustrated some different behavioural patterns, where the water-soluble micronutrient iodine to a large extent was incorporated into the vegetation and also transported further downstream into the lakes. The distribution of the macronutrient phosphorus was similar, but only a small quantity was transported from the terrestrial areas. The mass balance suggested a large retention of phosphorus at the catchment level, where a large part is retained in the vegetation. The heavy isotopes of thorium and uranium had their largest pools in the mineral soil and to a lesser extent in the humus layer. They showed a less mobile pattern with small amounts found in the vegetation or transported downstream. However, uranium was the element that had the highest export in relation to input of atmospheric deposition, suggesting a high weathering rate compared with thorium. Generally, it would be expected that weathering on these fairly young soils would be somewhat higher than the average for Sweden.

All of the elements show a higher export from the terrestrial ecosystems in the Laxemar-Simpevarp area than in the Forsmark area, except for uranium. Both phosphorus and iodine are known to precipitate in reactions with $CaCO_3$-rich soils /Greger 2004/, which dominate in the Forsmark area. Moreover, agricultural land is more abundant in Laxemar-Simpevarp, which may explain a higher export of phosphorus in Laxemar-Simpevarp.

11.3.3 Patterns of element distribution in ecosystems

The element distribution among the four compartments mineral soil, humus layer, producers and consumers showed consistent patterns between the sites. Most of the elements found in a higher content in the vegetation were nutrients. The nutrients are found in the group of the non-metals and in the group of metals. Many of the other elements found within the vegetation have analogous behaviour to nutrients and are therefore found accordingly. Other elements seem to be restricted to the fine roots within the producers compartment, such as U, Cd and Hg. Generally, small amounts were found in the consumer compartment and many elements were found to be below the detection limit within this compartment.

11.3.4 Long-term accumulation

The terrestrial vegetation type having the largest potential for long-term accumulation of elements is the wetland, where peat may accumulate under thousands of years. Comparisons suggest that the accumulation of organic material is somewhat higher at both the sites compared with national and boreal averages. With time, this higher accumulation will probably converge to average and later on decline further as they get older. However, the accumulation of organic matter in bogs will, in a safety assessment perspective, be of less importance due to the fact that the vegetation in bogs uses water from precipitation and not groundwater.

11.4 Uncertainitis in descriptions and estimates

This report describes the present conditions at the Forsmark and Laxemar-Simpevarp sites. Additionally, an historic aspect has also been included in order to deepen the understanding of the present configuration of the landscape and its land use.

The time-period for collecting field estimates have in many cases neither the spatial, nor, and perhaps more important, the temporal extension that would be desirable in a short-term perspective (e.g. 10 years). This implicates that the estimated variation for many parameters describing the site does not comprise the potential variation range, even though the estimated mean may be close to the true mean even for a longer time period. One way to compensate for this has been to consistently try to compare site data with other data found in the literature or to compare with modelled results. This has resulted in an extensive cross-validated site description of Forsmark and Laxemar-Simpevarp.

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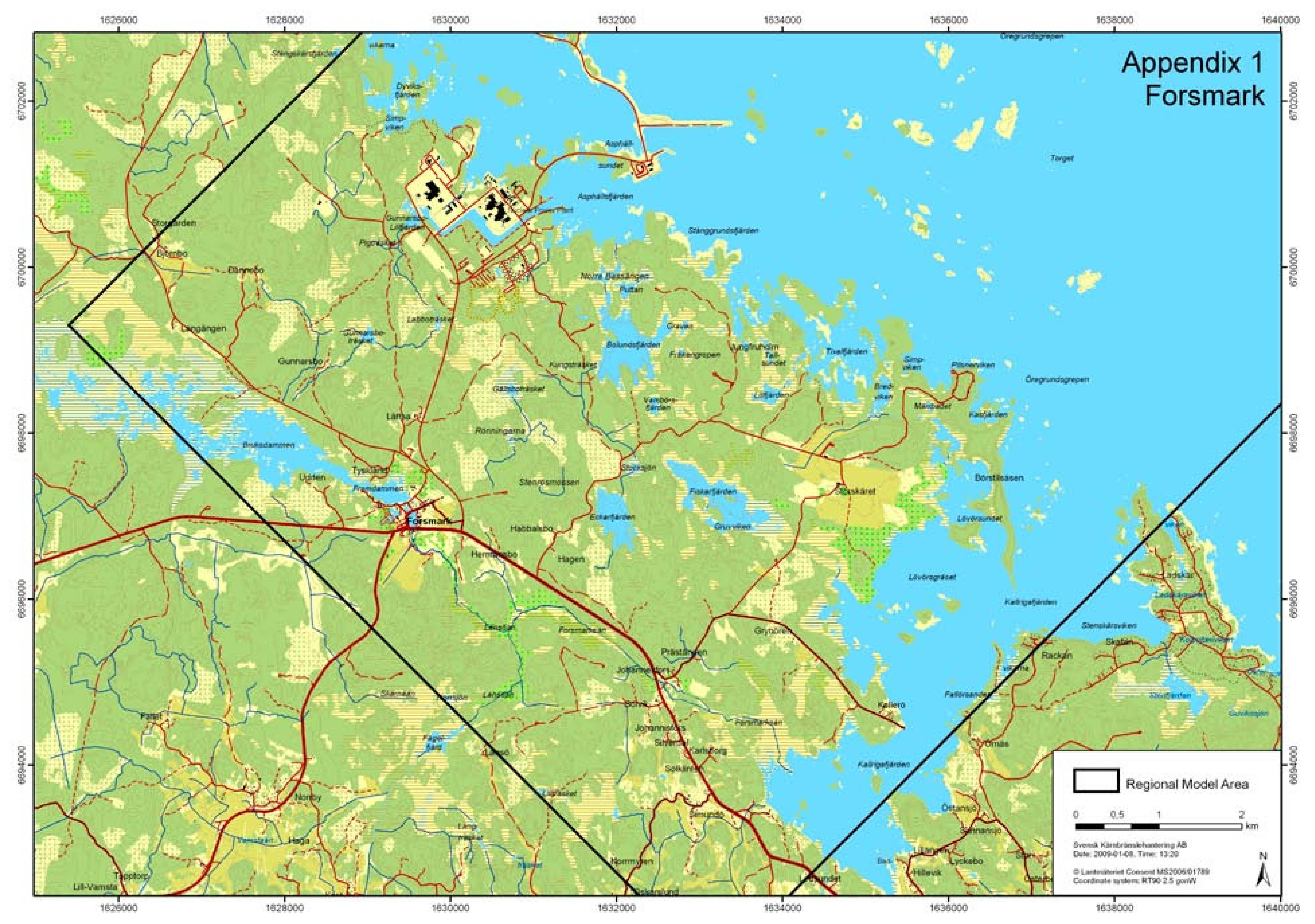
Appendix 1
Forsmark
1626000
1628000
1630000
1632000
1634000
1636000
1638000
1640000
6702000
6700000
6698000
6696000
6694000
Öregrundsgrepen
Asphällsundet
Asphällsfjärden
Stånggrundsfjärden
Torget
Storfjärden
Björnbo
Elanmeho
Långängen
Gunnarsbo
Labboträsket
Norra Bassängen
Puttan
Graven
Bolundsfjärden
Fräkengropen
Jungfruholm
Tixelfjärden
Pilsneviken
Kungsträsket
Gällbotträsket
Lillfjärden
Marbadet
Kastfjärden
Lärna
Bruksdammen
Rönningarna
Tyskland
Udden
Framdammen
Stenrosmossen
Forsmark
Fiskarfjärden
Stocksjön
Storskäret
Börstilsåsen
Lövörsundet
Habbalsbo
Eckarfjärden
Gunnarsboån
Hermansbo
Hagen
Lövörsgräset
Kallrigafjärden
Ladskär
Stenskärsviken
Skatan
Rackan
Forsmarksån
Grynöret
Prästängen
Johannisfors
Kallerö
Fallörsandet
Johannisdal
Karlsborg
Solkärret
Norrby
Haga
Tappforp
Lill-Vamsta
Sunnansjö
Östansjö
Lyckebo
Hillevik
Lövudden
Bergby
Normyren
Regional Model Area
0
0,5
1
2
km
Svensk Kärnbränslehantering AB
Date: 2009-01-08. Time: 13:20
© Lantmäteriet Consent MS2006/01789
Coordinate system: RT90 2.5 gonW
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Detailed map of Laxemar-Simpevarp

Appendix 3

A compilation of ecological studies performed in the Forsmark and Laxemar-Simpevarp investigation areas

A list of published studies that have been performed in the Forsmark (F) and Laxemar-Simpevarp (L) regional model areas. These are all available for download on the SKB website (www.skb.se).

Main subject	Specific subject	Site	Report	Reference
Vegetation	Vegetation map	F	R-02-06	/Boresjö Bronge and Wester 2002/
	Vegetation map	F/L	P-03-83	/Boresjö Bronge and Wester 2003/
	Validation of GIS	F	P-04-314	/Alling et al. 2004a/
	Remote sensing and LAI		R-04-24	/Boresjö Bronge 2004/
Key habitats	Nature values	F/L	R-04-12	/Kyläkorpi 2004/
	Survey	L	P-03-78	/Sturesson 2003/
	Survey	F	P-04-33	/Eklund 2004/
	Consequences	L	P-06-102	/Ignell et al. 2006/
	Consequences	F/L	P-06-109	/Wahlman et al. 2006/
Tree layer	Litter fall and litter decomposition	F/L	R-07-23	/Mjöfors et al. 2007/
	Birch on clear-cuts	F/L	P-04-315	/Alling et al. 2004c/
	LAI-index and tree stand data	F/L	TR-06-29	/Tagesson 2006/
	Tree parameters and field layer composition	F	P-03-81	/Abrahamsson 2003/
	Tree parameters and field layer composition	L	P-04-20	/Andersson 2004a/
	Dead wood	F	P-04-124	/Andersson 2004b/
	Dead wood	L	P-05-87	/Andersson 2005/
Field layer	Biomass	F	P-03-90	/Fridriksson and Öhr 2003/
	Biomass and production	F/L	P-05-80	/Löfgren 2005/
	Fungi	F	TR-04-26	/Johanson et al. 2004/
Root zone	Depth of roots	F	P-05-166	/Lundin et al. 2005b/
	Depth of roots	L	R-05-15	/Lundin et al. 2005a/
	Biomass and depth of fine roots	F/L	R-07-01	/Persson and Stadenberg 2007a/
	Turnover of fine roots	F	TR-07-11	/Persson and Stadenberg 2007b/
Respiration	Analysis 2003–2004	L	TR-06-28	/Tagesson 2006b/
	Analysis spring 2003 and LPJ-GUESS modelling	L	TR-06-41	/Tagesson 2006a/
	Method of calibration and analysis	F/L	R-06-125	/Tagesson 2006d/
	Measurements	L	P-06-278	/Lundkvist 2006/
	Measurements	F	P-07-23	/Heneryd 2007/
	Analysis 2004–2005	F/L	TR-07-13	/Tagesson 2007/
Wetlands	Properties and function		TR-04-08	/Kellner 2003/
	Inventory of vascular plants	F	P-06-115	/Göthberg and Wahlman 2006/
	Biomass estimates of *Phragmites australis*	L	P-04-316	/Alling et al. 2004b/

Main subject	Specific subject	Site	Report	Reference
Mammals	Mammal monitoring	F	P-03-18	/Cederlund et al. 2003/
	Mammal monitoring	F/L	P-04-04	/Cederlund et al. 2004/
	Bat monitoring	L	P-04-237	/Ignell 2004/
	Mammal monitoring	L	P-04-238	/Tannerfeldt and Thiel 2004/
	Bat monitoring	F	P-05-61	/de Jong and Gylje 2005/
	Rodent monitoring	L	P-05-84	/Cederlund et al. 2005a/
	Ecological data and carbon budget	F/L	R-05-36	/Truvé and Cederlund 2005/
	Mammal monitoring	F	P-05-151	/Cederlund 2005b/
	Moose monitoring	F	P-06-218	/Cederlund 2006a/
	Moose monitoring	F	P-06-219	/Cederlund et al. 2006b/
	Moose monitoring	L	P-06-228	/Cederlund et al. 2006c/
	Consequencis on hunting	L	P-07-09	/Cederlund and Truvé 2007/
	Surveys of mammal populations	F/L	P-07-122	/Truvé 2007/
	Moose monitoring	F	P-07-132	/Cederlund and Lemel 2007a/
	Moose monitoring	F	P-07-133	/Cederlund and Lemel 2007c/
	Moose monitoring	L	P-07-136	/Cederlund and Lemel 2007b/
	Moose monitoring	F	P-08-35	/Cederlund 2008a/
	Moose monitoring	F	P-08-36	/Cederlund 2008b/
	Moose monitoring	L	P-08-40	/Cederlund 2008c/
Birds	Monitoring	F	P-03-10	/Green 2003a/
	Monitoring	L	P-03-31	/Green 2003b/
	Monitoring	L	P-04-21	/Green 2004a/
	Monitoring	F	P-04-30	/Green 2004b/
	Monitoring	L	P-05-42	/Green 2005a/
	Monitoring	F	P-05-73	/Green 2005b/
	Monitoring	L	P-06-43	/Green 2006a/
	Monitoring	F	P-06-46	/Green 2006b/
	Monitoring	L	P-06-298	/Green 2006c/
	Monitoring	F	P-07-02	/Green 2007a/
	Monitoring	L	P-07-226	/Green 2007b/
	Monitoring	F	P-08-25	/Green 2008/
Invertebrates	Bioturbation	F/L	R-06-123	/Persson et al. 2007/
Groundwater fauna		F/L	TR-08-06	/Thulin and Hahn 2008/
Soils	Description	F	R-04-08	/Lundin et al. 2004/
	Description	L	R-05-15	/Lundin et al. 2005a/
Chemical characterisation	Deposits	F	P-05-15	/Lundin et al. 2005a/
	Biota and deposits	F	P-06-220	/Hannu and Karlsson 2006/
	Biota and deposits	L	P-06-320	/Engdahl et al. 2006/
	Deposits	L	P-06-321	/Lundin et al. 2006/
	Deposits	L	P-07-222	/Lundin et al. 2007/

Main subject	**Specific subject**	**Site**	**Report**	**Reference**
Ecosystem modelling	Workshop proceeding	F	R-04-71	/Lindborg and Kautsky 2004/
	LPJ-GUESS modelling of carbon	L	R-06-41	/Tagesson 2006a/
	Coup modelling of forest ecosystems	F/L	R-06-45	/Gustafsson et al. 2006/
	Coup modelling of carbon and water in terrestrial ecosystems	L	R-06-121	/Karlberg et al. 2006/
Description of surface systems	General description of biosphere	F	R-05-03	/Lindborg 2005/
	General description of biosphere	L	R-06-11	/Lindborg 2006/
A descriptive ecosystem model	Terrestrial biosphere model	F	R-01-09	/Jerling et al. 2005/
	Strategy description		R-03-06	/Löfgren and Lindborg 2003/
Ecosystem description	Literature survey	F	R-02-08	/Berggren and Kyläkorpi 2002a/
	Literature survey	L	R-02-10	/Berggren and Kyläkorpi 2002b/
	Variables for surface ecosystems		R-00-33	/Kyläkorpi et al. 2000/
	Variables for surface ecosystems		R-00-19	/Lindborg and Kautsky 2000/

Appendix 4

Biomass and consumption of birds at the two sites.

This data is presented further in Section 4.2.2 and have been used to calculate the bird consumption in the food webs. Data is based on inventories of the regional model area during the breeding season for the Forsmark area 2002–2004 and the Laxemar-Simpevarp area 2003 and 2004 /Green unpubl./. The species were divided into five different functional groups in the first column according to their main food preference (Figure 4-33). Food selection by different species was found on the website of the Swedish Ornithological Association /SOF 2007, www/ and the Danish Ornithological Association /DOF 2007, www/ and /Jonsson 1992/. The different bird species were divided into groups depending on which habitat they mainly gather their food from: woodland (W), open land (O), lake (L), sea 1 (S1) or sea 2 (S2; S= S1+S2) (see Table 4-36 for definitions). The number of eggs laid were found on the website of the Danish Ornithological Association /DOF 2007, www/. The breeding period in days was calculated based on the number of months (30 days for all months) given in /Jonsson 1992/ or on the website of the Swedish Ornithological Association. The breeding period varied between 120 days, for species migrating to the south of Sahara or a similar distance, and 365 days for non-migratory bird species. The body mass of the species was mainly taken from /Green unpubl./, but in some cases body mass was taken from the Danish ornithological association website /DOF 2007, www/. Constants for the equation describing the field metabolic ratio were provided for the systematic/functional groups: passerines, Charadriiformes, Galliformes, marine birds, insectivores and omnivores and temperate forest birds. The group carnivores was assigned values representative for the category "All birds" in lieu of better estimates.

Species	Number of territories Forsmark	Laxemar-Simpevarp	Habitat	Number of eggs	Breeding period (days)	Body mass (g)	Systematic group/order (in /Nagy et al. 1999/)
Carnivores							
Marsh Harrier (Brun kärrhök)	5	2	L+S1	5	150	585	All birds
Sparrow Hawk (Sparvhök)	12	19	W	4	365	204	All birds
Northern Goshawk (Duvhök)	3	7	W	3.5	365	1,140	All birds
Common Buzzard (Ormvråk)	14	22	W	3.5	240	856	All birds
Pygmy Owl (Sparvuggla)	15	13	W	6	365	58	All birds
Ural Olw (Slaguggla)	4		W	4	365	730	All birds
Tengmalms Owl (Pärluggla)	1	2	W	5	365	143	All birds
Tawny Owl (Kattuggla)	16	56	O	4	365	472	All birds
Raven (Korp)	13	30	W	5	365	1,100	All birds
Insectivores							
Velvet Scoter (Svärta)	7	5	S	11	210	1,588	Marine birds
Common Shelduck (Gravand)	5	1	L+S1	9	210	1,152	Marine bird
Honey Buzzard (Bivråk)	6	9	O	1.5	120	626	Insectivores
Eurasian Hobby (Lärkfalk)	7	8	O	2.5	150	236	Insectivores
Northern Lapwing (Tofsvipa)	25	1	O	4	240	218	Charadriiform^{es}
Eurasian Oystercatcher (Strandskata)	25	10	L+S1	3	210	526	Charadriiformes

Species	Number of territories Forsmark	Laxemar-Simpevarp	Habitat	Number of eggs	Breeding period (days)	Body mass (g)	Systematic group/order (in /Nagy et al. 1999/)
Common Ringed Plover (Större strandpipare)	18	5	L+S1	4	210	64	Charadriiformes
Common Snipe (Enkelbeckasin)	182	100	L+S1	4	210	116	Charadriiformes
Common Redshank (Rödbena)	37	5	L+S1	4	180	122	Charadriiformes
Green Sandpiper (Skogssnäppa)	54	100	L+S1	4	180	80	Charadriiformes
Curlew (Storspov)	3		L+S1	4.5	105	725	Charadriiformes
Common Sandpiper (Drillsnäppa)	35	120	L+S1	4	210	48	Charadriiformes
Eurasian Woodcock (Morkulla)	91		W	4	240	312	Charadriiformes
Wryneck (Göktyta)	45	25	W	8	150	40	Insectivores
Grey-headed Woodpecker (Gråspett)	1		W	6.5	365	128	Insectivores
Black Woodpecker (Spillkråka)	13	30	W	4.5	365	380	Insectivores
Lesser Spotted Woodpecker (Mindre hackspett)	13	19	W	5	365	23	Insectivores
Three-toed Woodpecker (Tretåig hackspett)	2		W	4	365	66	Insectivores
Great spotted woodpecker (Större hackspett)	54	330	W	6	365	85	Passeriformes
Green Woodpecker (Gröngöling)	20	65	W	6	365	218	Passeriformes
River Warbler (Flodsångare)	1		W	6	90	18	Passeriformes
Greenish Warbler (Lundsångare)	1		W	5	120	10	Passeriformes
Red-breasted Flycatcher (Mindre flugsnappare)	5	5	W	4.5	120	9	Passeriformes
Song Thrush (Taltrast)	1,050	2,500	W	5.5	180	64	Passeriformes
Tree Pipit (Trädpiplärka)	460	2,900	W	5	150	23	Passeriformes
Winter Wren (Gärdsmyg)	410	800	W	7	240	9	Passeriformes
Dunnock (Järnsparv)	550	910	W	4.5	210	19	Passeriformes
Common Redstart (Rödstjärt)	45	400	W	6.5	180	15	Passeriformes
European robin (Rödhake)	2,500	5,500	W	6	210	17	Passeriformes
Redwing (Rödvingetrast)	270		W	5.5	210	68	Passeriformes
Garden Warbler (Trädgårdssångare)	680	1,200	W	4.5	150	19	Passeriformes
Blackcap (Svarthätta)	200	1,500	W	5	180	18	Passeriformes
Icterine Warbler (Härmsångare)	15	10	W	5	150	13	Passeriformes
Wood Warbler (Grönsångare)	180	1,000	W	6	150	11	Passeriformes
Common Chiffchaff (Gransångare)	91		W	6	180	8	Passeriformes

Species	Number of territories Forsmark	 Laxemar-Simpevarp	Habitat	Number of eggs	Breeding period (days)	Body mass (g)	Systematic group/order (in /Nagy et al. 1999/)
Willow Warbler (Lövsångare)	3,900	12,000	W	6.5	150	9	Passeriformes
Goldcrest (Kungsfågel)	1,320	3,500	W	18	365	6	Passeriformes
European Pied Flycatcher (Svartvit flugsnappare)	230	600	W	6	150	13	Passeriformes
Spotted Flycatcher (Grå flugsnappare)	460	2,000	W	4.5	150	15	Passeriformes
Eurasian Treecreeper (Trädkrypare)	540	1,200	W	5.5	365	9	Passeriformes
Long-tailed Tit (Stjärtmes)	50	60	W	9.5	365	8	Passeriformes
Red-backed Shrike (Törnskata)	60	100	O	5.5	120	28	Insectivores
Wheatear (Stenskvätta)	6	12	O	1.5	150	24	Passeriformes
Grashopper Warbler (Gräshoppsångare)	1	1	O	5	120	13	Passeriformes
Common Cuckoo (Gök)	29	100	O	5	150	112	Passeriformes
Common Swift (Tornseglare)	100	500	O	2.5	120	42	Passeriformes
Barn swallow (Ladusvala)	10	150	O	4.5	180	19	Passeriformes
House Martin (Hussvala)	50	200	O	4.5	180	18	Passeriformes
Meadow Pipit (Ängspiplärka)	7		O	6	180	18	Passeriformes
White Wagtail (Sädesärla)	270	500	O	6	180	21	Passeriformes
Black Redstart (Svart rödstjärt)	1		O	5	210	16	Passeriformes
Thrush Nightingale (Näktergal)	4	40	O	5	150	24	Passeriformes
Whinchat (Buskskvätta)	34	10	O	6	150	17	Passeriformes
Eurasian Reed-Warbler (Rörsångare)	180	400	O	4	150	12	Passeriformes
Sedge Warbler (Sävsångare)	180	5	O	4.5	150	10	Passeriformes
Marsh Warbler (Kärrsångare)	1	1	O	4	150	12	Passeriformes
Greater Whitethroat (Törnsångare)	45	250	O	5	150	14	Passeriformes
Lesser Whitethroat (Ärtsångare)	270	600	O	4	150	12	Passeriformes
Eurasian Nightjar (Nattskärra)		70	O	2	150	85	Passeriformes
Rock Pipit (Skärpiplärka)		7	O	5	180	23	Passeriformes
Herbivores							
Mute Swan (Knölsvan)	69	55	L+S1	7	365	10,750	All birds
Greylag Goose (Grågås)	49	120	L+S1	4.5	240	3,464	All birds
Canada Goose (Kanadagås)	26	3	L+S1	6	365	3,450	All birds
Mallard (Gräsand)	104	150	L+S1	11	365	1,024	All birds
Eurasian Wigeon (Bläsand)	1		L+S1	9	180	700	All birds

	Number of territories						
Species	**Forsmark**	**Laxemar-Simpevarp**	**Habitat**	**Number of eggs**	**Breeding period (days)**	**Body mass (g)**	**Systematic group/order (in /Nagy et al. 1999/)**
Green-winged Teal (Kricka)	30	10	L+S1	10	180	360	All birds
Stock dove (Skogsduva)	10	13	W	2	210	301	Temperate forest
Eurasian Bullfinch (Domherre)	230	150	W	5	365	31	Passeriformes
Hawfinch (Stenknäck)	10	9	W	4.5	365	54	Passeriformes
Red Crossbill (Mindre korsnäbb)	200	100	W	4	365	38	Passeriformes
Parrot Crossbill (Större korsnäbb)	50	10	W	4	365	52	Passeriformes
Rock Pigeon (Stadsduva)	10	20	O	2	365	304	Passeriformes
Piscivorer							
Blackthroated Diver (Storlom)	6	2	L+S	2	150	2,806	Marine bird
Bittern (Rördrom)	4		L+S1	5	240	1,231	Marine bird
Gray Heron (Häger)		85	L+S1	4	210	1,800	Charadriiformes
White-tailed Eagel (Havsörn)	4	2	L+S	2	365	4,793	Marine bird
Osprey (Fiskgjuse)	8	4	L+S	3.5	150	1,528	Marine bird
Common Merganser (Storskrake)	168	50	L+S1	9.5	365	1,355	Marine bird
Great Crested Grebe (Skäggdopping)	37	65	L+S1	3.5	180	875	Marine bird
Red-breasted Merganser (Småskrake)	5	11	L+S1	8.5	365	1,129	Marine bird
Great Cormorant (Storskarv)	121		S	4	365	2,184	Pelecaniformes
Lesser Black-backed Gull (Sillltrut)	97	27	L+S	3	210	715	Charadriiformes
Herring gull (Gråtrut)	272	98	L+S1	2.5	365	1,060	Charadriiformes
Common gull (Fiskmås)	184	75	L+S1	3	210	386	Charadriiformes
Parasitic Jaeger (Labb)	4	1	S	3	180	384	Charadriiformes
Razorbill (Tordmule)	3	4	S	1	210	717	Charadriiformes
Black Gillemot (Tobisgrissla)	50		L+S1	1	365	378	Charadriiformes
Common Tern (Fisktärna)	95	30	L+S1	2.5	105	126	Charadriiformes
Artic Tern (Silvertärna)	234	167	S	2	120	110	Charadriiformes
Caspian Tern (Skräntärna)		1	L+S	2	150	675	Charadriiformes
Omnivores (herbivores/insectivores)							
Common Eider (Ejder)	144	150	S1	5.5	210	2,066	Marine bird
Turnstone (Roskarl)	10	5	S1	3.5	120	113	Charadriiformes
Black-headed Gull (Skrattmås)	143	56	L+S1	3	240	266	Charadriiformes
Little Gull (Dvärgmås)	2		L	3	180	120	Charadriiformes
Great Black-backed Gull (Havstrut)	29	27	L+S1	3	365	1,606	Charadriiformes
Shoveler (Skedand)	6	1	L+S1	8.5	120	560	Omnivore
Pochard (Brunand)	1		L+S1	8.5	213	869	Omnivore
Spotted Crake (Småfläckig sumphöna)	3	1	L	10.5	120	90	Omnivore

Species	Number of territories		Habitat	Number of eggs	Breeding period (days)	Body mass (g)	Systematic group/order (in /Nagy et al. 1999/)
	Forsmark	Laxemar-Simpevarp					
Whooper Swan (Sångsvan)	5	4	L+S1	4	240	9,375	Omnivore
Gadwall (Snatterand)	4	1	L+S1	10	210	775	Omnivore
Tufted Duck (Vigg)	52	35	L+S1	9	365	750	Omnivore
Common Goldeneye (Knipa)	83	50	L+S1	9	365	962	Omnivore
Water Rail (Vattenrall)	8	2	L+S1	2	240	116	Omnivore
Eurasian Coot (Sothöna)	1		L+S1	7.5	365	732	Omnivore
Hazelhen (Järpe)	30	10	W	7.5	365	370	Galliformes
Black Grouse (Orre)	20	20	W	7	365	1,106	Galliformes
Capercaillie (Tjäder)	6	10	W	7.5	365	2,931	Galliformes
Marsh Tit (Entita)	20	400	W	8	365	12	Passeriformes
Nutcracker (Nötkråka)	7	15	W	4	365	192	Passeriformes
Eurasian Blackbird (Koltrast)	1,100	3,200	W	4	365	93	Passeriformes
Chaffinch (Bofink)	4,300	11,000	W	4	210	24	Passeriformes
Fieldfare (Björktrast)	50	42	W	5.5	365	105	Passeriformes
Mistle Thrush (Dubbeltrast)	23	300	W	5	210	118	Passeriformes
Great tit (Talgoxe)	860	2,200	W	9	365	18	Passeriformes
Eurasian Blue Tit (Blåmes)	100	1,200	W	10	365	11	Passeriformes
Coal Tit (Svartmes)	360	1,200	W	9	365	9	Passeriformes
Crested Tit (Tofsmes)	500	900	W	6.5	365	11	Passeriformes
Willow Tit (Talltita)	460	450	W	7.5	365	11	Passeriformes
Common Wood-Pigeon (Ringduva)	180	1,000	W	2	210	510	Omnivore
Eurasian Siskin (Grönsiska)	1,050	1,200	W	5	365	12	Passeriformes
European Greenfinch (Grönfink)	320	600	W	5	365	30	Passeriformes
Eurasian Nuthatch (Nötväcka)	120	700	W	6.5	365	23	Passeriformes
Eurasian Jay (Nötskrika)	90	200	W	6.5	365	170	Passeriformes
Hooded crow (Kråka)	45	50	W	4.5	365	550	Passeriformes
Quail (Vaktel)	1		O	9	105	99	Galliformes
Ring-necked Pheasant (Fasan)	1	60	O	14	365	1,000	Galliformes
Scarlet Rosefinch (Rosenfink)	50	7	O	4.5	120	23	Passeriformes
Linnet (Hämpling)	5	6	O	5.5	180	19	Passeriformes
Ortolan Bunting (Ortolansparv)	1		O	4.5	120	25	Passeriformes
Wood Lark (Trädlärka)	2	40	O	4	180	30	Passeriformes
Skylark (Sånglärka)	11	7	O	4	240	36	Passeriformes
Crane (Trana)	20	29	O	2	150	5,300	Omnivore
Eurasian Jackdaw (Kaja)	50	100	O	5	365	226	Passeriformes
Eurasian Magpie (Skata)	10	30	O	7	365	210	Passeriformes
European Starling (Stare)	50	500	O	4	365	80	Passeriformes

Species	Number of territories Forsmark	Laxemar-Simpevarp	Habitat	Number of eggs	Breeding period (days)	Body mass (g)	Systematic group/order (in /Nagy et al. 1999/)
House Sparrow (Gråsparv)	20	100	O	4.5	365	28	Passeriformes
Eurasian Tree Sparrow (Pilfink)	50	200	O	4	365	20	Passeriformes
European Goldfinch (Steglits)	3	2	O	5.5	365	16	Passeriformes
Reed Bunting (Sävsparv)	180	200	O	5	365	20	Passeriformes
Yellowhammer (Gulsparv)	500	1,500	O	4.5	365	30	Passeriformes

Appendix 5

Data for calculation of energi budgets of amphibians and reptiles (in Swedish)

Underlag till
Energiflöden i ekosystem med grod- och kräldjur
2004-10-27

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A5.1 Beskrivning av arbetsuppgiften

För arter av grod- och kräldjur inom Simpevarp och Forsmark särskilda undersökningsområden (12 st, se tidigare rapporter) lämnas här uppgifter rörande;

1/ Genomsnittsvikt hos en vuxen individ. Normalt finns inte dessa uppgifter i litteraturen utan enbart storlek i form av längd. Jag har kollat runt med folk som håller dessa arter i fångenskap. Jag har utgått från en jämn könsfördelning i populationen, vilket stämmer ungefär för kräldjuren men inte alltid lika väl hos groddjuren. I allmänhet finns lite fler hanar eftersom dessa blir könsmogna vid lägre ålder. Ofta är honan betydligt större än hanen, särskilt hos vanlig snok, huggorm, och vanlig padda. Den angivna vikten är ett mått där jag försökt väga in dessa förhållanden för respektive art.

2/ Täthet av individer/ha. Mycket svårt att ge en riktigt bra siffra främst beroende på att dessa djur inte finns jämt fördelade i landskapet utan är knutna till speciella mikromiljöer eller finns radiärt i fläckar med rätt biotop runt en lekdamm, eller längs kantzoner i landskapet. För de flesta arterna finns det inga undersökningar gjorda som ger stöd för min uppskattning. Här är alltså osäkerheten ganska stor.

3/ Typ av föda. Relativt enkelt. Dessa uppgifter finns normalt i litteraturen.

4/ Energibehov/dag under den aktiva säsongen. Beakta att alla arterna har en aktiv säsong av varierande längd. Under denna tid har de en relativt hög energiomsättning. Under övervintringen sänker de sin metabolism till nästan 0 och i sammanhanget kan denna energiförbrukning negligeras. Alla upptagna arter är rovdjur och man räknar med att 90% av energin i födan kan utnyttjas (för växtätare är siffran mindre än 60%). Jag har lämnat uppgift om ungefärligt antal dagar per år som arterna är aktiva.

5/ Fortplantningskapacitet. Antalet ungar per hona och år. Vissa reptiler får ungar enbart vartannat år men siffran anger genomsnitt per år. Många groddjur lägger extremt många ägg, av vilka en mycket stor andel dör innan metamorfos till landliv (ofta 95–99%). Därefter dör cirka 30% av de metamorfoserade per år fram till vuxen ålder (2–3 år normalt). Grodorna reproducerar sig i snitt en eller två gånger under sin livstid. Paddor och salamandrar 3–4 gånger. Ödlorna 2–3 gånger och ormarna 3–4 gånger under sitt liv. Antalet ungar eller ägg hos en hona beror i stor utsträckning på hennes storlek (ålder) och den mängd energi hon lyckats samla i sina fettkroppar (ett speciellt organ) inför varje reproduktiv säsong.

A5.1.1 Förhållanden som ytterligare komplicerar arbetsuppgiften

Längden på den aktiva perioden varierar mellan arterna, med avseende på vilken breddgrad vi är och mellan år beroende på vädersituation (främst temperatur). Hos groddjuren är det extra komplicerat att ange rimliga värden, dels beroende på att det i stor utsträckning saknas sådan information i litteraturen, dels därför att de även som vuxna tillbringar en kortare eller längre del av säsongen i vatten och resterande tid på land. Hur lång tid de jagar i dessa två miljöer beror på tillgången på lämplig föda som varierar mellan år och typer av vatten och landmiljö. Typen av bytesdjur är också olika i vatten- respektive landmiljön.

En ytterligare komplikation är att både grod- och kräldjur har en mycket oregelbunden förekomst i landskapet. Dels måste man känna till vilken typ av landmiljö som är optimal eller i alla fall godtagbar. För groddjur måste man veta hur långt arten maximalt vandrar radiärt från lekdammen och på vilket avstånd lämplig miljö finns och hur stora dessa fläckar är. Många arter av kräldjur finns främst längs kanter i landskapet eller där solinstrålningen är tillräckligt hög för att ge optimal kroppstemperatur. Många kräldjur fungerar så att om temperaturen ett år är ovanligt låg (tillåter inte optimal energiomsättning vid bytesfångst till exempel), så sänker de sin metabolism och går under mark. På samma sätt kan det vara om bytestätheten sjunker kraftigt så ställer de ner metabolismen kraftigt och går under mark (en motsvarighet till vintervila men beroende på födobrist). En huggorm kan t ex svälta ett år utan problem, det finns ofta stora fettreserver att ta av eller så resorberas ägg och ungar.

Hos ödlor generellt beräknas energiförbrukningen vara 4–30 mg torr vikt foder per gram levande ödla per dag. Den högre siffran avser perioder av hög aktivitet. Biomassa hos populationer av smaödlor i ett Nordamerikanskt landskap var 27 (12–49) g per ha, och hos en annan art 61–97 g per ha. Biomassa hos ormar i ett savannområde var 150 g per ha. Denna typ av uppgifter saknas för svenska arter och jag har inte funnit motsvarande uppgifter för vår landskapstyp heller.

I beräkningen nedan har energiförbrukningen hos ormar beräknats vara 10 mg torrvikt foder per dag per gram levande vikt av ormen. Motsvarande siffror för ödlor beräknas vara 20 mg och hos groddjuren 5 mg. Skillnaderna beror främst på olika kroppstemperatur hos de olika djurgrupperna som är högst hos ödlor och betydligt lägre hos groddjur. Undersökningar visar att energiomsättningen påverkas starkt av aktivitetstemperaturen hos ett djur.

A5.2 Arter

A5.2.1 Mindre vattensalamander

Vuxenvikt 3 gram, byten i vattnet är större djurplankton och diverse vattenlevande insekter och spindeldjur, byten på land är främst mjuka ryggradslösa djur som daggmask och sniglar eller insektslarver. Det finns inga beräkningar av täthet men i medeltal i fiskfria småvatten så leker cirka 200 vuxna/100 m^2 vattenyta. Populationerna varierar normalt mellan några hundra och upp till cirka 10 000 individer. När de sedan går upp på land sprider de sig radiärt från några tiotals meter till cirka 300 m från vattnet och förekommer i ganska varierad landmiljö. Hur långt de går beror ofta på födotillgång. Tätheten kan uppskattas om man utgår från befintliga småvatten och drar en cirkel runt vattnet med en radie av 300 m (räknat från vattenlinjen). Räkna ut ytan och dela med antalet djur som uppskattas till 200/100 m^2 vattenyta (dock max 10 000 ind). Det finns alltså inte salamandrar spridda jämt i landskapet, dock finns enstaka individer som vandrar längre sträckor mellan dammar. Antal aktiva dagar/år är cirka 200 (varav 60–90 i lekvattnet och resterande i fuktig landmiljö). Vuxna djur är nattaktiva. Förekommer främst i fiskfria vatten. Populationsstorleken kan variera med flera tiopotenser beroende på närvaro eller avsaknad av rovfisk. Energibehov hos ett vuxet djur under en säsong motsvarar 3 × 5 mg × 200 dagar = 3 000 mg torrvikt foder per individ. Antalet ägg i snitt 350 per säsong.

A5.2.2 Större vattensalamander

Vuxenvikt 9 gram, byten i vattnet är vattenlevande insekter och spindeldjur, men också grodlarver och larver av den mindre vattensalamandern, byten på land daggmask, sniglar och insektslarver. Beräkning av täthet görs enligt samma modell men här räknas med endast 100 ind/100 m^2 och en spridningszoon som är 500 m från dammens vattenkant. Totalpopulationen är sällan över några tusen djur. Denna art har större krav på landmiljön och finns främst i områden med gammal skog med förmultnande ved på marken och gärna blockrik och öppen terräng mellan gamla träd. Antal aktiva dagar/år är cirka 170. Energibehov motsvarar

9 × 5 mg × 170 dagar = 7 650 mg torrvikt foder per individ under säsongen. Antalet ägg i snitt 400 per säsong, men endast 50% överlever till larv beroende på genetisk defekt hos arten, det vill säga antalet ägg bör justeras till 200.

A5.2.3 Vanlig padda

Vuxenvikt hona 80 gram, hane 40 gram, i genomsnitt 60 gram. Äter alla smådjur (insekter, spindlar, maskar mm) som rör sig. Ungefärligt antal vuxna per hektar cirka 40 per hektar och utspridda mer jämt i landskapet jämfört med grodorna och salamandrarna, även i lite torrare marker. Antal aktiva dagar/år är cirka 220. Energibehov motsvarar 80 × 5 mg × 220 dagar = 123 200 mg torrvikt foder per individ under säsongen. Antalet ägg i snitt 4 000 per säsong.

A5.2.4 Åkergroda

Vuxenvikt cirka 20 gram. Äter alla smådjur (insekter, spindlar, maskar mm) som rör sig. Ungefärligt antal vuxna per hektar är 30 st inom 100 m från lekdammens strandkant, 10 st inom 100–300 m från damm och 1–5 inom 300–500 m från lekdamm. Antal aktiva dagar/år är cirka 200. Energibehov motsvarar 20 × 5 mg × 200 dagar = 20 000 mg torrvikt foder per individ under säsongen. Antalet ägg i snitt 1 500 per säsong.

A5.2.5 Vanlig groda

Vuxenvikt 25 gram. Äter alla smådjur (insekter, spindlar, maskar mm) som rör sig. Obs! Förekommer endast i Forsmark. Ungefärligt antal vuxna per hektar är 20 st inom 100 m från lekvattnets strand, 10 st inom 100–300 m och 5 inom 300–500 m. Antal aktiva dagar/år är cirka 220. Energibehov motsvarar 25 × 5 mg × 220 dagar = 27 500 mg torrvikt foder per individ under säsongen. Antalet ägg i snitt 2 000 per säsong.

A5.2.6 Gölgroda

Vuxenvikt 20 gram. Äter alla smådjur (insekter, spindlar, maskar mm) som rör sig. Finns endast i Forsmark och helt knuten till dammar. I rapporten finns angivet fyra dammar där arten påträffats och ungefärliga antalet vuxna djur varierar mellan 50 och 100 per damm. Antal aktiva dagar/år är cirka 170. Energibehov motsvarar 20 × 5 mg × 170 dagar = 17 000 mg torrvikt foder per individ under säsongen. Antalet ägg i snitt 1 700 per säsong.

A5.2.7 Sandödla

Vuxenvikt 8 gram. Äter spindlar och olika insekter. Lever i små isolerade kolonier med 10–30 vuxna inom en yta av cirka ett hektar. Dessa små kolonier ligger glest utspridda och i Simpevarp kom jag i kontakt med en sådan koloni. Utslaget på hela området 0.1–0.2 vuxna per hektar. Antal aktiva dagar/år är cirka 170. Energibehov motsvarar 8 × 20 mg × 170 dagar = 27 200 mg torrvikt foder per individ under säsongen. Antalet ägg i snitt cirka 10 per säsong.

A5.2.8 Skogsödla

Vuxenvikt 5 gram. Äter spindlar och olika insekter. Täthet uppskattas till 5 vuxna per hektar. Antal aktiva dagar/år är cirka 210. Energibehov motsvarar 5 × 20 mg × 210 dagar = 21 000 mg torrvikt foder per individ under säsongen. Föder levande ungar, cirka 7 per säsong.

A5.2.9 Kopparödla

Vuxen vikt 15 gram. Äter främst daggmask och sniglar. Täthet uppskattas till 10 vuxna per hektar. Antal aktiva dagar/år är cirka 200. Energibehov motsvarar 15 × 20 mg × 200 dagar = 60 000 mg torrvikt foder per individ under säsongen. Föder levande ungar, cirka 8 per säsong.

A5.2.10 Hasselsnok

Vuxenvikt 70 gram. Äter främst andra reptiler såsom kopparödla. Täthet uppskattas till 0.2 vuxna per hektar. Antal aktiva dagar/år är cirka 200. Energibehov motsvarar 70 × 10 mg × 200 dagar = 140 000 mg torrvikt foder per individ under säsongen. Föder levande ungar, cirka 12 vid varje födsel vartannat år, det vill säga cirka 6 per säsong.

A1.2.11 Snok

Vuxenvikt 50–80 gram hos hane och 100–300 gram hos hona. Utgående från ett litet överskott av hanar anges medelvikten till 175 gram per vuxen. Äter främst grodor, paddor, salamandrar och fisk. Täthet uppskattas till 2 vuxna/hektar i områden med fuktiga marker (där många bytesobjekt finns) och 1 vuxen/hektar i torrare marker. Antal aktiva dagar/år är cirka 200. Energibehov motsvarar 175 × 10 mg × 200 dagar = 350 000 mg torrvikt foder per individ under säsongen. Lägger ägg varje år, cirka 13 ägg per säsong.

A1.2.12 Huggorm

Vuxenvikt 100 gram hos hane och 200 gram hos honan, genomsnitt per vuxen 150 gram (jämn könskvot), äter främst sork och möss (cirka 1 gnagare/15 dagar under 150 dagar). Huggormen äter inte hela den aktiva perioden utan endast under cirka 70% av den aktiva perioden om 220 dagar per år. Täthet uppskattas till 1vuxen/hektar, i igenväxande ängsmarker med hög tthet av smågnagare upp till 4 vuxna per hektar. Energibehov motsvarar 150 × 10 mg × 220 dagar = 330 000 mg torrvikt foder per individ under säsongen. Föder levande ungar, cirka 10 vartannat år, det vill säga 5 per säsong i genomsnitt.

Appendix 6

Species list Forsmark

The mammals, birds, amphibians and reptiles are well-described for the sites (see references in table). However, the plant lists should not be regarded as complete and is put together using mainly the reports /Andersson 2004, Göthberg and Wahlman 2006, Johanson et al. 2004/. These cover more of the commonand typical species for the area.

Latin	Swedish
Mammals	**Däggdjur**
See Table 4-24 and 4-29	
Birds	**Fåglar**
See Appendix 4	
Amphibians and reptiles	**Grod- och kräldjur**
See Table 4-43	
Vascular plants	**Kärlväxter**
Acer platanoides	Lönn
Achillea millefolium	Rölleka
Agrimonia eupatoria	Småborre
Agrostis canina	Brunven
Agrostis capillaris	Rödven
Agrostis stolonifera	Krypven
Alchemilla sp	Daggkåpor
Alnus glutinosa	Klibbal
Andromeda polifolia	Rosling
Anemone nemorosa	Vitsippa
Angelica sylvestris	Strätta
Anthoxanthum odoratum	Vårbrodd
Anthriscus sylvestris	Hundkex
Arrhenatherum elatius	Knylhavre
Athyrium filix-femina	Majbräken
Berberis vulgaris	Berberis
Betula pendula	Vårtbjörk
Betula pubescens	Glasbjörk
Brachypodium sylvaticum	Lundskafting
Briza media	Darrgräs
Calamagrostis arundinacea	Piprör
Calamagrostis canescens	Grenrör
Calamagrostis epigejos	Bergrör
Calamagrostis purpurea	Brunrör
Calamagrostis stricta	Madrör
Callitriche stagnalis	Dikeslånke
Calluna vulgaris	Ljung
Caltha palustris	Kabbeleka
Campanula patula	Ängsklocka
Campanula persicifolia	Stor Blåklocka
Cardamine pratensis	Ängsbräsma
Carex acuta	Vasstarr
Carex appropinquata	Tagelstarr
Carex buxbaumii	Klubbstarr
Carex canescens	Gråstarr
Carex capillaris	Hårstarr

Latin	**Swedish**
Carex caspitosa	Tuvstarr
Carex cuprina	Blankstarr
Carex diandra	Trindstarr
Carex digitata	Vispstarr
Carex disticha	Plattstarr
Carex elata	Bunkestarr
Carex elongata	Rankstarr
Carex flacca	Slankstarr
Carex flava	Knagglestarr
Carex globularis	Klotstarr
Carex lasiocarpa	Trådstarr
Carex lepidocarpa	Näbbstarr
Carex limosa	Dystarr
Carex nigra	Hundstarr
Carex nigra/juncella	Styltstarr
Carex ovalis	Harstarr
Carex pallescens	Blekstarr
Carex panicea	Hirsstarr
Carex pseudocyperus	Slokstarr
Carex pulicaris	Loppstarr
Carex pulicaris	Loppstarr
Carex rostrata	Flaskstarr
Carex vesicaria	Blåsstarr
Centarium littorale	Kustarun
Centaurea jacea	Rödklint
Cerastium fontanum	Hönsarv
Chrysosplenium alternifolium	Gullpudra
Circaea alpina	Dvärghäxört
Cirsium arvense	Åkertistel
Cirsium helenioides	Brudborste
Cirsium palustre	Kärrtistel
Cirsium vulgare	Vägtistel
Coeloglossum viride	Grönkulla
Convallaria majalis	Liljekonvalj
Crepis paludosa	Kärrfibbla
Cypripedium calceolus	Guckusko
Dactylis glomerata	Hundäxing
Dactylorhiza fuchsii	Skogsnycklar
Dactylorhiza incarnata	Ängsnycklar
Danthonia decumbens	Knägräs
Daphne mezereum	Tibast
Dapne mezereum	Tibast
Deschampsia cespitosa	Tuvtåtel
Deschampsia flexuosa	Kruståtel
Drosera anglica	Storsileshår
Drosera rotundifolia	Rundsileshår
Dryopteris carthusiana	Skogsbräken
Dryopteris cristata	Granbräken
Dryopteris filix-mas	Träjon
Eleocharis quinqueflora	Tagelsäv
Eleocharis uniglumis	Agnsäv
Elymus caninus	Lundelm
Elytrigia juncea	Strandkvickrot

Latin	Swedish
Elytrigia repens	Kvickrot
Empetrum nigerum	Kråkbär
Epilobium adenocaulon	Amerikansk dunört
Epilobium angustifolium	Mjölkört
Epilobium palustre	Kärrdunört
Epipactis helleborine	Skogsknipprot
Epipactis palustris	Kärrknipprot
Equisetum arvense	Åkerfräken
Equisetum fluviatile	Sjöfräken
Equisetum palustre	Kärrfräken
Equisetum pratense	Ängsfräken
Equisetum scirpoides	Trådfräken
Equisetum sylvaticum	Skogsfräken
Equisetum variegatum	Smalfräken
Eriophorum angustifolium	Ängsull
Eriophorum vaginatum	Tuvull
Eupatorium cannabinum	Hampflockel
Euphrasia frigida	Fjällögontröst
Festuca arundinacea	Rörsvingel
Festuca ovina	Fårsvingel
Festuca rubra	Rödsvingel
Filipendula ulmaria	Älggräs
Filipendula vulgaris	Brudbröd
Fragaria vesca	Smultron
Frangula alnus	Brakved
Fraxinus excelsior	Ask
Galeopsis bifida	Toppdån
Galium album	Stormåra
Galium boreale	Vitmåra
Galium palustre	Vattenmåra
Galium uliginosum	Vattenmåra
Galium verum	Gulmåra
Gentianella uliginosa	Sumpgentiana
Geranium robertianum	Stinknäva
Geranium sanguineum	Blodnäva
Geranium sylvaticum	Midsommarblomster
Geum rivale	Humleblomster
Glaux maritima	Strandkrypa
Glechoma hederacea	Jordreva
Glyceria fluitans	Mannagräs
Goodyera repens	Knärot
Gymnocarpium dryopteris	Ekbräken
Hepatica nobilis	Blåsippa
Hieracium grp silvaticiforma	Skogsfibbla
Hieracium umbellatum	Flockfibbla
Hierocloë odorata	Ängsmyskgräs
Hippophae rhamnoides	Havtorn
Huperzia selago	Lopplummer
Hypericum maculatum	Fyrkantig Johannesört
Hypericum perforatum	Äkta johannesört
Hypochoeris maculata	Slåtterfibbla
Inula salicina	Krissla
Iris pseudacorus	Svärdslilja

Latin	**Swedish**
Juncus articulatus	Ryltåg
Juncus balticus	Östersjötåg
Juniperus communis	En
Knautia arvensis	Åkervädd
Lactuca sativa	Skogssallat
Lathyrus linifolius	Gökärt
Lathyrus pratensis	Gulvial
Lathyrus vernus	Vårärt
Ledum palustre	Skvattram
Lemna minor	Andmat
Leontodon autumnalis	Höstfibbla
Leucanthemum vulgare	Prästkrage
Linaria vulgaris	Gulmåra
Linnaea borealis	Linnea
Listera ovata	Tvåblad
Lithospermum officinale	Stenfrö
Lonicera xylosteum	Skogstry
Luzula pallescens	Blekfryle
Luzula pilosa	Vårfryle
Lycopodium annotinum	Revlummer
Lycopus europaeus	Strandklo
Lysimachia thyrsiflora	Topplösa
Lysimachia vulgaris	Videört
Lythrum salicaria	Fackelblomster
Maianthemum bifolium	Ekorrbär
Malus sylvestris	Vildapel
Melampyrum nemorosum	Natt och dag
Melampyrum sylvaticum	Skogskovall
Melica nutans	Bergsslok
Mentha aquatica	Vattenmynta
Mentha arvensis	Åkermynta
Menyanthes trifoliata	Vattenklöver
Milium effusum	Hässlebrodd
Molinia caerulea	Blåtåtel
Monotropa hypopitys	Tallört
Myosotis sylvatica	Skogsförgätmigej
Myrica gale	Pors
Ophioglossum vulgatum	Ormtunga
Origanum vulgare	Kungsmynta
Orthilia secunda	Björkpyrola
Oxalis acetosella	Harsyra
Paris quadrifolia	Ormbär
Parnassia palustris	Slåtterblomma
Pedicularis palustris	Kärrspira
Peucedanum palustre	Kärrsilja
Phegopteris connectilis	Hultbräken
Phleum pratense	Timotej
Phragmites australis	Vass
Picea abies	Gran
Pimpinella saxifraga	Bockrot
Pinguicula vulgaris	Tätört
Pinus sylvestris	Tall
Plantago lanceolata	Svartkämpar
Plantago maritima	Gulkämpar

Latin	**Swedish**
Platanthera bifolia	Nattviol
Plathanthera chlorantha	Grönvit nattviol
Poa nemoralis	Lundgröe
Poa palustris	Sengröe
Poa pratensis	Ängsgröe
Poa trivialis	Kärrgröe
Polygala vulgaris	Jungfrulin
Polygonatum multiflorum	Storrams
Polygonatum odoratum	Getrams
Polypodium vulgare	Stensöta
Populus tremula	Asp
Potentilla anserina	Gåsört
Potentilla erecta	Blodrot
Potentilla palustris	Kråkklöver
Potentilla reptans	Revfingerört
Primula farinosa	Majviva
Primula veris	Gullviva
Prunella vulgaris	Brunört
Prunus padus	Hägg
Pteridium aquilinum	Örnbräken
Puccinellia capillaris	Saltgräs
Puccinellia distans	Grått saltgäs
Pulmonaria obscura	Lungört
Pyrola chlorantha	Grönpyrola
Pyrola rotundifolia	Vitpyrola
Quercus robur	Ek
Ranunculus acris	Vanlig Smörblomma
Ranunculus flammula	Ältranunkel
Ranunculus lingua	Sjöranunkel
Ranunculus repens	Revsmörblomma
Rhododendron tomentosum	Skvattram
Rhynchospora alba	Vitag
Ribes alpinum	Måbär
Roegneria canina	Lundelm
Rosa canina	Nyponros
Rubus caesius	Blåhallon
Rubus chamaemorus	Hjortron
Rubus idaeus	Hallon
Rubus saxatilis	Stenbär
Rumex acetosa	Ängssyra
Sagittaria natans	Trubbpilblad
Salix aurita	Bindvide
Salix caprea	Sälg
Salix cinerea	Gråvide
Salix myrsinifolia	Svartvide
Salix pentandra	Jolster
Salix repens	Krypvide
Sanicula europaea	Sårläka
Satureja vulgare	Bergmynta
Satureja vulgaris	Bergmynta
Schoenoplectus lacustris	Säv
Schoenus ferrugineus	Axag
Scrophulaira nodosa	Flenört

Latin	Swedish
Sedum telephium	Kärleksört
Selaginella selaginoides	Dvärglummer
Sesleria caerulea	Älväxing
Silene dioica	Rödblära
Solanum dulcamara	Besksöta
Solidago virgaurea	Gullris
Sonchus arvensis	Åkermolke
Sorbus aucuparia	Rönn
Sorbus intermedia	Oxel
Sparganium natans	Dvärgigelknopp
Stachys sylvatica	Stinksyska
Stellaria graminea	Grässtjärnblomma
Stellaria longifolia	Skogsstj.blomma
Stellaria nemorum ssp nemorum	Nordlundarv
Succisa pratensis	Ängsvädd
Taraxacum sp	Maskros
Thalictrum flavum	Ängsruta
Thalictrum simplex	Backruta
Thelypteris palustris	Kärrbräken
Trichophorum alpinum	Snip
Trientalis europaea	Skogsstjärna
Trifolium medium	Skogsklöver
Trifolium pratense	Rödklöver
Triglochin maritima	Havssälting
Triglochin palustre	Kärrsälting
Tussilago farfara	Tussilago
Typha latifolia	Bredkaveldun
Ulmus glabra	Alm
Utricularia intermedia	Dybläddra
Utricularia vulgaris	Vattenbläddra
Vaccinium myrtillus	Blåbär
Vaccinium oxycoccos	Tranbär
Vaccinium uliginosum	Odon
Vaccinium vitis-idaea	Lingon
Valeriana sambucifolia	Strandvänderot
Veronica chamaedrys	Teveronika
Veronica officinalis	Ärenpris
Veronica scutellata	Dyveronika
Viburnum opulus	Olvon
Vicia cracca	Kråkvicker
Vicia sepium	Häckvicker
Vicia sylvatica	Skogsvicker
Viola canina	Ängsviol
Viola mirabilis	Underviol
Viola palustris	Kärrviol
Viola riviniana	Skogsviol
Bryophytes	**Mossor**
Aneura pinguis	Fetbålmossa
Antitrichia curtipendula	Fällmossa
Brachythecium sp	Gräsmossor
Calliergion sp	Skedmossor
Calliergionella sp	Spjutmossor

Latin	Swedish
Campylium sp	Spärrmossor
Climacium dendroides	Palmmossa
Dichelyma sp	Klomossor
Dicranum sp	Kvastmossor
Drepanocladus sp	Krokmossor
Helodium blandowii	Kärrkammossa
Herzogiella striatella	Spretmossor
Hylocomium splendens	Husmossa
Hypnum cupressiforme	Cypressfläta (Bergklomossa)
Lophozia sp	Flikmossor
Mnium sp	Stjärnmossor
Plagiochila asplenioides	Praktbräkenmossa
Pleurozium schreberi	Väggmossa
Polytrichum sp	Björnmossor
Pseudotaxiphyllum elegans	Platt skimmermossa
Ptilidium pulcherrinum	Tät franslevermossa
Ptilium crista-castrensis	Kammossa
Rhytidiadelphus triquetrus	Kranshakmossa
Scorpidium scorpioides	Korvspionmossa
Sphagnum sp	Vitmossor
Thuidium sp	Tujamossor
Tomentypnum nitens	Gyllenmossa
Warnstorfia exannulata	Kärrkrokmossa
Lichens	**Lavar**
Cladonia arbuscula	Gulvit renlav
Cladonia rangiferina	Grå renlav
Cladonia stellaria	Fönsterlav
Hypogymnia sp	Blåslavar
Peltigera sp	Filtlavar
Platismatia sp	Näverlavar
Rhizocarpon sp	Kartlavar
Fungi	**Svampar**
Cordyceps ophioglossioides	Smal svampklubba
Geastrum sp	Jordstjärna
Cantharellus aurora	Rödgul trumpetsvamp
Phellodon niger	Svart taggsvamp
Hydnellum suavolens	Dofttaggsvamp
Hydnellum ferrugineum	Dropptaggsvamp/Skarp droptaggsvamp
Hygrocybe sp	Hagvaxskivling
Sarcodon imbricatus	Fjällig taggsvamp
Lactarius deterrimus	
Suillus granulatus	
Lactarius scrobiculatus	
Boletus edulis	
Cortinarius odorifer	
Sarcodon imbricatus	
Cantharellus tubaeformis	
Lactarius trivialis	
Cortinarius armeniacus	
Hypholoma capnoides	
Tricholoma equestre	
Collybia peronata	

Appendix 7

Species list Laxemar-Simpevarp

The mammals, birds, amphibians and reptiles are well-described for the sites (see references in table). However, the plant lists should not be regarded as complete and is put together using mainly the report /Andersson 2004/. This list cover more of the common and typical species for the area.

Latin	Swedish
Mammals	**Däggdjur**
See Table 4-24 and 4-29	
Birds	**Fåglar**
See Appendix 4	
Amphibians and reptiles	**Grod- och kräldjur**
See Table 4-44	
Vascular plants	**Kärlväxter**
Acer platanoides	Lönn
Achillea millefolium	Rölleka
Achillea ptarmica	Nysört
Agrostis canina	Brunven
Agrostis capillaris	Rödven
Agrostis gigantea	Storven
Allium oleraceum	Backlök
Alnus glutinosa	Klibbal
Andromeda polifolia	Rosling
Anemone nemorosa	Vitsippa
Anthoxanthum odoratum	Vårbrodd
Athyrium filix-femina	Majbräken
Betula pendula	Vårtbjörk
Betula pubescens	Glasbjörk
Calamagrostis arundinacea	Piprör
Calamagrostis epigejos	Bergrör
Calluna vulgaris	Ljung
Campanula persicifolia	Stor Blåklocka
Campanula rotundifolia	Ängsklocka
Carex acuta	Vasstarr
Carex diandra	Trindstarr
Carex echinata	Stjärnstarr
Carex lasiocarpa	Trådstarr
Carex nigra	Hundstarr
Carex ovalis	Harstarr
Carex rostrata	Flaskstarr
Cirsium arvense	Åkertistel
Cirsium palustre	Kärrtistel
Convallaria majalis	Liljekonvalj
Convolvulus arvensis	Åkervinda
Corylus avellana	Hassel
Crataegus laevigata	Rundhagtorn
Cystopteris fragilis	Stenbräken
Dactylis glomerata	Hundäxing
Danthonia decumbens	Knägräs
Daucus carota	Vildmorot

Latin	**Swedish**
Deschampsia cespitosa	Tuvtåtel
Deschampsia flexuosa	Kruståtel
Dryopteris carthusiana	Skogsbräken
Dryopteris filix-mas	Träjon
Elytrigia repens	Kvickrot
Empetrum nigrum	Kråkbär
Epilobium adenocaulon	Amerikansk dunört
Epilobium angustifolium	Mjölkört
Eriophorum vaginatum	Tuvull
Festuca ovina	Fårsvingel
Festuca rubra	Rödsvingel
Fragaria vesca	Smultron
Fraxinus excelsior	Ask
Juniperus communis	En
Lamium purpureum	Rödplister
Lathyrus pratensis	Gulvial
Ledum palustre	Skvattram
Linaria vulgaris	Gulsporre
Linnaea borealis	Linnea
Luzula pilosa	Vårfryle
Lycopodium annotinum	Revlummer
Lysimachia vulgaris	Videört
Maianthemum bifolium	Ekorrbär
Malus sylvestris	Vildapel
Matricaria perforata	Baldersbrå
Melampyrum pratense	Ängskovall
Melampyrum sylvaticum	Skogskovall
Melica nutans	Bergsslok
Mentha arvensis	Åkermynta
Milium effusum	Hässlebrodd
Moehringia trinervia	Skogsnarv
Molinia caerulea	Blåtåtel
Monotropa hypopitys	Tallört
Nardus stricta	Stagg
Oxalis acetosella	Harsyra
Phleum pratense	Timotej
Phragmites australis	Vass
Picea abies	Gran
Picea abies	Gran
Pinus sylvestris	Tall
Poa annua	Vitgröe
Poa compressa	Berggröe
Poa nemoralis	Lundgröe
Polypodium vulgare	Stensöta
Populus tremula	Asp
Potentilla erecta	Blodrot
Potentilla palustris	Kråkklöver
Primula veris	Gullviva
Prunus spinosa	Slån
Pteridium aquilinum	Örnbräken
Quercus robur	Ek
Ranunculus acris	Vanlig Smörblomma
Ribes alpinum	Måbär

Latin	Swedish
Roegneria canina	Lundelm
Rosa canina	Nyponros
Rubus idaeus	Hallon
Rubus nessensis	Skogsbjörnbär
Rubus saxatilis	Stenbär
Rumex acetosella	Bergssyra
Salix caprea	Sälg
Salix cinerea	Gråvide
Salix cinerea	Gråvide
Salix myrsinifolia	Svartvide
Sedum telephium	Kärleksört
Senecio viscosus	Klibbkorsört
Silene dioica	Rödblära
Solidago virgaurea	Gullris
Sorbus aucuparia	Rönn
Sorbus intermedia	Oxel
Stachys sylvatica	Stinksyska
Stellaria graminea	Grässtjärnblomma
Stellaria longifolia	Skogsstj.blomma
Taraxacum sp	Maskros
Thalictrum sp	Thalictrum sp
Trientalis europaea	Skogsstjärna
Trifolium medium	Skogsklöver
Trifolium pratense	Rödklöver
Trifolium repens	Vitklöver
Tussilago farfara	Tussilago
Urtica dioica	Brännässla
Vaccinium myrtillus	Blåbär
Vaccinium vitis-idaea	Lingon
Verbascum thapsus	Kungsört
Veronica chamaedrys	Teveronika
Veronica officinalis	Ärenpris
Vicia cracca	Kråkvicker
Vicia sepium	Häckvicker
Vicia sylvatica	Skogsvicker
Vincetoxicum hirundinaria	Tulkört
Viola palustris	Kärrviol
Viola riviniana	Skogsviol
Viola tricolor	Styvmorsviol
Bryophytes	**Mossor**
Calliergion sp	Skedmossor
Calliergionella sp	Spjutmossor
Climacium dendroides	Palmmossa
Dicranum sp	Kvastmossor
Drepanocladus sp	Krokmossor
Drepanocladus uncinatus	Krokmossa
Grimmia trichophylla	Kuddmossa
Hylocomium splendens	Husmossa
Hypnum cupressiforme	Cypressfläta
Mnium sp	Stjärnmossor
Pleurozium schreberi	Väggmossa
Polytrichum sp	Björnmossor

Latin	Swedish
Ptilium crista-castrensis	Kammossa
Rhytidiadelphus triquetrus	Kranshakmossa
Sphagnum sp	Vitmossor
Lichens	**Lavar**
Cetraria ericetorum	Smal inlandslav
Cetraria islandica	Islandslav
Cladina sp	Renlavar
Cladina arbuscula	Gulvit renlav
Cladina rangiferina	Grå renlav
Cladonia sp	Bägarlavar
Cladonia stellaria	Fönsterlav
Peltigera sp	Filtlavar
Fungi	**Svampar**
Antrodia pulvinascens	Veckticka
Bankera fuligineoalba	Talltaggsvamp
Bankera violascens	Grantaggsvamp
Clavulina cristata	Kamfingersvamp
Craterellus cornucopioides	Svart trumpetsvamp
Gyromitra infula	Biskopsmössa
Heterobasidion annosum	Rotticka
Hydnellum aurantiacum	Orange taggsvamp
Inonotus tomentosus	Luddticka
Lactarius zonarioides	Granriska
Laetiporus sulphureus	Svavelticka
Macrolepicata procera	Stolt fjällskivling
Mycena galericulata	Rynkhätta
Phellinus pini	Tallticka
Phellodon tomentosus.	Trattaggsvamp
Sarcodon imbricatus	Fjällig taggsvamp (tallvar.)
Sarcodon scabrosus	Skrovlig taggsvamp
Sarcodon squamosus	Fjällig taggsvamp (granvar.)
Sarcodon versipellis	Brödtaggsvamp
Scleroderma citrinum	Vitgul rottryffel
Sparassis crispa	Blomkålssvamp

Appendix 8

Photographs of the ecosystems described in Chapter 6

Detailed investigations of carbon pools and fluxes were undertaken in six different ecosystems (see Chapter 6). Below are pictures from four of the six ecosystems.

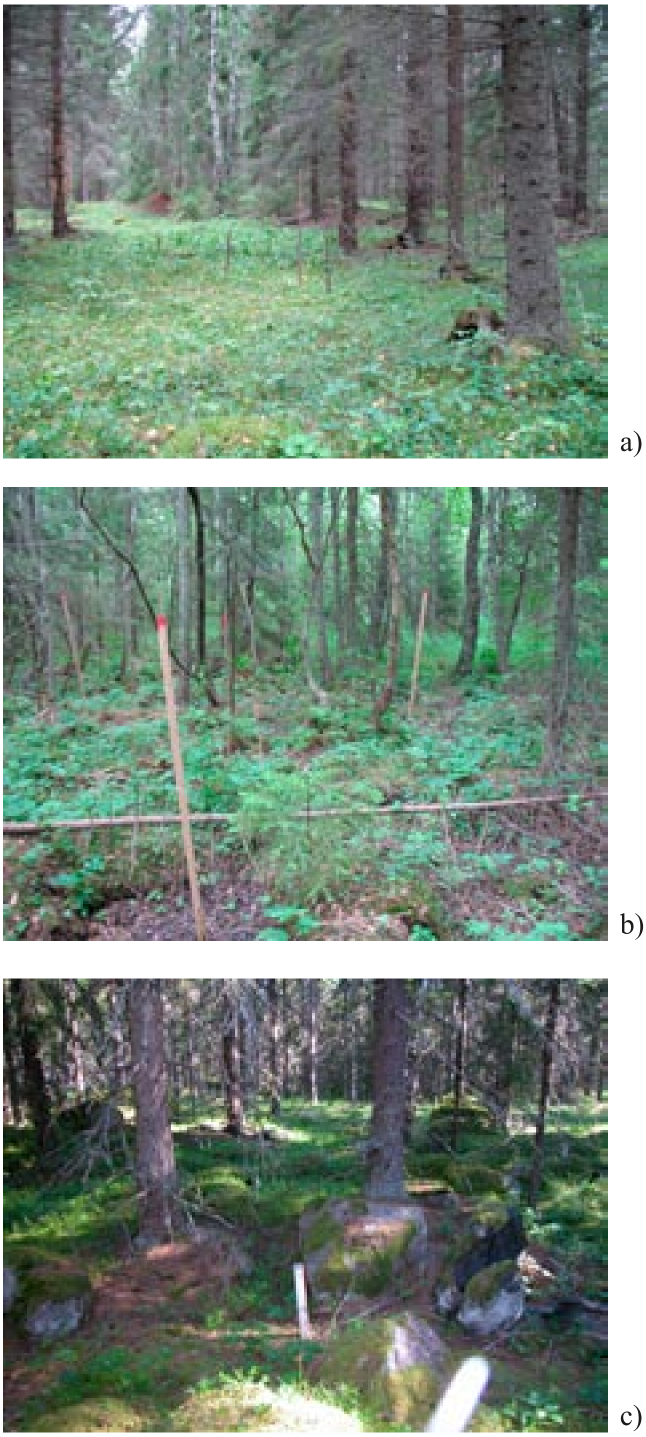


Figure A8-1. *Two investigated ecosystems in the Forsmark regional model area. a) Herb-rich Norway spruce (Picea abies) forest (FG1), b) Norway spruce – Alder (Alnus glutinosa) wetland forest (SS1), c) Norway spruce forest (B2a). Photo: Sara Nordén*

Figure A8-2. *Two investigated ecosystems in the Laxemar-Simpevarp regional model area. a) Norway spruce forest on ditched peat land (G1), b) oak (Quercus robur) forest (L1), c) alder wetland (S1) close to the sea shore. Photo: Sara Nordén*

Appendix 9

Atmospheric deposition

Below is data listed describing the expected atmospheric deposition for Forsmark (Table A6-1) and Laxemar-Simpevarp (A6-2) for a number of different elements.

Table A9-1. Expected atmospheric deposition for a number of different elements at Forsmark (dry deposition and/or precipitation). Data from 1) /Tröjbom and Söderbäck 2006a/, 2) /Phil-Karlsson et al. 2003/, 3) /Tyler and Olsson 2006/, 4) /Sicada October 2007/.

Element	Precipitation (mm year^{-1})	Deposition (g m^{-2} year^{-1})	Reference	Comment
C	559	1.26	1	Precipitation, site data, mean from two stations (PFM002457 and PFM 002564).
N	559	0.36	2	Precipitation, site data only include data from 1 sampling occasion and therefore generic data is used. Station Jädraås.
P	559	0.012	1	Precipitation, site data, mean from two stations (PFM002457 and PFM 002564).
U	559	0.000002	3	Estimate of atmospheric deposition during the winter period in a deciduous forest in southern Sweden.
Th	559	0.000005	3	Estimate of atmospheric deposition during the winter period in a deciduous forest in southern Sweden.
I	559	0.00028	1	Precipitation, based on two measurements at the site that were both below the detection limit of 1µg/l. Half the detection limit was assumed to be the deposition, which was in the lower range of the iodine deposition interval reported by /Sheppard et al 2002/.
Al	559	1.76E–05	1	Precipitation, site data, mean from two stations (PFM002457 and PFM 002564).
Br	559	0.0014	1	Precipitation, based on 12 measurements at the site that were all below the detection limit of 5µg/l. Half the detection limit was assumed to be the deposition.
Ca	559	0.17	1	Precipitation, site data, mean from two stations (PFM002457 and PFM 002564).
Cl	559	0.51	1	Precipitation, site data, mean from two stations (PFM002457 and PFM 002564).
Fe	559	0.018	1	Precipitation, site data, mean from two stations (PFM002457 and PFM 002564).
Mg	559	0.046	1	Precipitation, site data, mean from two stations (PFM002457 and PFM 002564).
K	559	0.098	1	Precipitation, site data, mean from two stations (PFM002457 and PFM 002564).
Si	559	0.0084	1	Precipitation, based on one measurement at the site that was below the detection limit of 30µg/l. Half the detection limit was assumed to be the deposition.
Na	559	0.30	1	Precipitation, site data, mean from two stations (PFM002457 and PFM 002564).
S	559	0.28	1	Precipitation, site data, mean from two stations (PFM002457 and PFM 002564).
Mn	559	0.013	4	Precipitation, based on site investigation in Laxemar-Simpevarp but with precipitation amounts for Forsmark.
Sr	559	0.0047	4	Precipitation, based on site investigation in Laxemar-Simpevarp but with precipitation amounts for Forsmark.

Table A9-2. Expected atmospheric deposition for a number of different elements at Laxemar-Simpevarp. Data from 1) /Phil-Karlsson et al. 2008/, 2) /Knape 2001/, 3) /Tyler and Olsson 2006/, 4) /Tröjbom and Söderbäck 2006b/, 5) /Sicada October 2007/.

Element	Precipitation (mm y^{-1})	Deposition (g m^{-2} y^{-1})	Reference	Comment
C	600	1.88	1	Precipitation, generic data from station Rockneby in Kalmar län mean 2000-20007.
N	600	0.64	1	I Precipitation, generic data from station Rockneby in Kalmar län mean 2000-20007.
P	600	0.027	2	Generic data from Äspö.
U	600	0.000002	3	Estimate of atmospheric deposition during the winter period in a deciduous forest in southern Sweden.
Th	600	0.000005	3	Estimate of atmospheric deposition during the winter period in a deciduous forest in southern Sweden.
I	600	0.0003	4	Precipitation, based on two measurements in Forsmark that were both below the detection limit of 1µg/l. Half the detection limit was assumed to be the deposition, which was in the lower range of the interval reported by /Sheppard et al. 2002/. Corrected for precipitation amount in Laxemar-Simpevarp.
Al	600	1.89E–05	4	Precipitation, based on site investigation in Forsmark but with precipitation amounts for Laxemar-Simpevarp.
Br	600	0.083	5	Precipitation, site data, mean from two stations (PSM002170 and PSM001516) n=105, Sept 2002–Oct. 2007
Ca	600	0.42	5	Precipitation, site data, mean from two stations (PSM002170 and PSM001516) n=30, Sept. 2002–Oct. 2007.
Cl	600	0.74	5	Precipitation, site data, mean from two stations (PSM002170 and PSM001516) n=104, Sept. 2002–Oct. 2007. 1 outlier was removed from the original dataset.
Fe	600	0.038	5	Precipitation, site data, mean from two stations (PSM002170 and PSM001516) n=30, Sept. 2002–Oct. 2007.
Mg	600	0.13	5	Precipitation, site data, mean from two stations (PSM002170 and PSM001516) n=30, Sep 2002–Oct 2007.
K	600	0.36	5	Precipitation, site data, mean from two stations (PSM002170 and PSM001516) n=30, Sep 2002–Oct 2007.
Si	600	0.033	5	Precipitation, site data, mean from two stations (PSM002170 and PSM001516) n=30, Sept. 2002–Oct. 2007.
Na	600	1.03	5	Precipitation, site data, mean from two stations (PSM002170 and PSM001516) n=30, Sept. 2002–Oct. 2007.
S	600	0.345	5	Precipitation, site data, mean from two stations (PSM002170 and PSM001516) n=30, Sept. 2002–Oct. 2007.
Mn	600	0.014	5	Precipitation, site data, mean from two stations (PSM002170 and PSM001516) n=29, Sept. 2002–Oct. 2007.
Sr	600	0.0051	5	Precipitation, site data, mean from two stations (PSM002170 and PSM001516) n=30, Sept. 2002–Oct. 2007.
Li	600	0.0015	5	Precipitation, based on 30 measurements at the site that were below the detection limit, half the detection limit was used in the estimate, Sept. 2002–Nov. 2017.
F	600	0.071	5	Precipitation, site data, mean from two stations (PSM002170 and PSM001516) n=30, Sept. 2002–Oct. 2007.

Statistical descriptions of wetlands, agricultural land and forest stands

Data in GIS has been used to identify and describe wetlands, agricultural land and forests stands. The main source for identifying the terrestrial objects within the regional model area has been a vegetation map /Boresjö Bronge and Wester 2003/. See Appendix I in /Lindborg (ed.) 2006/ for detailed information of methods and data for Laxemar-Simpevarp. The same procedure was also undertaken to characterize the Forsmark area. All work in GIS has been done using the ESRI Inc. software ArcView 3, ArcGIS 8.3 and 9.1 with extensions /ESRI 2005/, and all statistics has been calculated using Statistica 6.0 /StatSoft Inc 2001/.

Each property is described using number of observations, mean, median, min, max, lower and upper quartile, and standard deviation. Finally, is a distribution curve presented for the parameter data. No transformation of the data has been performed before calculating the descriptive statistics.

Table A10-1. Area and catchment area statistics for the wetlands in Forsmark and Laxemar-Simpevarp.

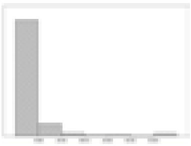
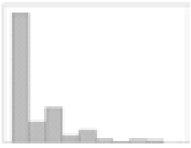
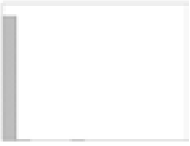
Property	N	Mean	Median	Minimum	Maximum	Lower Quartile	Upper Quartile	Std.Dev.	Distribution
Forsmark									
Area (m^2)	148	37,367	10,766	996	815,763	4,604	32,216	87,727	
Catchment area (m^2)	148	737,400	102,900	500	12,975,400	28,300	401,100	1,822,351	
Laxemar-Simpevarp									
Area (m^2)	536	9,600	3,400	20	391,700	2,100	6,800	28,800	
Catchment area (m^2)	534	1,326,000	30,100	0	81,210,300	10,300	127,500	7,987,500	

Table A10-2. Area and catchment area statistics for agricultural land in Forsmark and Laxemar-Simpevarp.

Property	N	Mean	Median	Minimum	Maximum	Lower Quartile	Upper Quartile	Std.Dev.	Distribution
Forsmark									
Area (m^2)	153	32,020	4,516	397	1,077,217	2,003	12,691	121,367	
Catchment area (m^2)	153	242,091	21,900	100	4.53·106	5,700	97,500	777,650	
Laxemar-Simpevarp									
Area (m^2)	1,175	12,200	4,900	50	242,000	2,300	12,500	21,600	
Catchment area (m^2)	1,175	1.52·106	56,000	0	92.45·106	11,000	0.32·106	6.38·106	

Table A10-3. Area and catchment area statistics for forest stands in Forsmark and Laxemar-Simpevarp.

Property	N	Mean	Median	Minimum	Maximum	Lower Quartile	Upper Quartile	Std.Dev.	Distribution
Forsmark									
Catchment area	1,000	15,805	200	0	5,884,500	0	600	229,880	
Laxemar-Simpevarp									
Catchment area	1,000	110,400	200	0	45,303,500	0	600	1,964,200