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March 2001

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*Keywords:* SFR, Safe, Ecosystems, Biosphere, Vegetation, Model.

This report concerns a study which was conducted for SKB. The conclusions and viewpoints presented in the report are those of the author(s) and do not necessarily coincide with those of the client.

# Abstract

This report is a part the SKB project "SAFE" (Safety Assessment of the Final Repository of Radioactive Operational Waste). The aim of project SAFE is to update the previous safety analysis of SFR-1. SFR-1 is a facility for disposal of low and intermediate level radioactive waste, which is situated in bedrock beneath the Baltic Sea, 1 km off the coast near the Forsmark nuclear power plant in Northern Uppland. The reports "Project SAFE – Update of the SFR-1 safety assessment Phase 1." /Andersson et al.,1998a/ and "Project SAFE – Update of the SFR-1 safety assessment Phase 1 Appendices."/Andersson et al., 1998b/ gives an overview of the SAFE project and presents the work that has to be performed to achieve the goal of the project /cf. Holmgren and Karlén, 1998; Brydsten, 1999; Kumblad, 1999/.

A part of the SAFE-analysis aims at analysing the transport of radionuclides in the ecosystems. To do so one has to build a model that includes a large amount of information concerning the biosphere. The first step is to collect and compile descriptions of the biosphere. This report is a first attempt to characterise the terrestrial environment of the SFR area of Forsmark. In the first part of the report the terrestrial environment, land class distribution and production of the area is described. The primary production in different terrestrial ecosystems is estimated for a model area in the Forsmark region. The estimations are based on the actual land class distribution and the values for the total primary production (d.w. above ground biomass) and the amount carbon (C) produced, presented as $g/m^2$ for each land class respectively.

An important aspect of the biosphere is the vegetation and its development. The future development of vegetation is of interest since production, decomposition and thus storage of organic material, vary strongly among vegetation types and this has strong implications for the transport of radionuclides. Therefore an attempt to describe the development of terrestrial vegetation has been made in the second part.

Any prediction of future vegetation is based on knowledge of the past together with premises for the future development. The predictions made, thus, becomes marred with errors enforced by the assumptions and incomplete information of the past. The assumptions made for the predictions in this report are crude and results in a coarse model of the future vegetation. To make this fully clear we have included a description of past development of environmental conditions and vegetation as a key to understand the discrepancy between past events and predictions of the future. Thus, the part dealing with the development of vegetation is started by a description of the past, followed by a prediction of future vegetation.

The history of vegetation shows that the development is an interaction between changes in climate, shore displacement, local vegetation development and human activities. Differences in plant community structure can, to a large extent, be related to climatic change. When it got warmer and more humid, nemoral (thermophilous) species immigrated, and the distribution of land classes changed on a regional scale. The most important factors for the change of the biotic environment and plant community has been human impact and climate change, while shore displacement rather has an effect locally and on a short time scale. In the premises for future development of vegetation change in climate and most of human activities are omitted.

A general outline of the anticipated future development of the vegetation is described. There will be a major change in the vegetation of the area from year 3000 to 4000 in that vast areas will be transformed from aquatic to terrestrial. This probably means that new accumulation areas for water transported materials are formed. With the transformation from aquatic to terrestrial environment more stable sinks will be formed such as lakes and mires. In these organic material will be accumulated and carbon will be concentrated to particular areas. In year 5000 practically no aquatic areas are to be found and at this stage very small amount of organic material will leave the area except by water transport and by gases. Since the mobility is higher in dryer areas where the organic material is decomposed at a faster rate one will expect an increased mobility whereas in wetlands the mobility will be reduced. Therefore, the balance between the wet and dry ecosystems, and hence the mobility of carbon, is hard to predict without a more detailed estimation of future land classes. Environmental factors such as humidity and temperature affect the processes involved and warmer climate, for example, will reduce the accumulation, whereas cool and humid instead speed it up.

# Sammanfattning


Denna rapport är en del av SKB projektet "SAFE" (Safety Assessment of the Final Repository of Radioactive Operational Waste). Målet är att uppdatera en tidigare analys SFR-1. SFR-1 är ett förvar för lågt och intermediärt riskavfall beläget i bergrum under Östersjön 1 km utanför kusten vid Forsmarks kärnkraftverk i Norra Uppland. I rapporterna "Project SAFE – Update of the SFR-1 safety assessment Phase 1." /Andersson et al., 1998a/ och "Project SAFE – Update of the SFR-1 safety assessment Phase 1 Appendices."/Andersson et al., 1998b/ ges en översikt av SAFE-projektet och här presenteras vad som måste göras för att nå projektets mål /cf. Holmgren and Karlén, 1998; Brydsten, 1999a,b; Kumblad, 1999/.

En viktig del i SAFE-analysen är att analysera hur radionuklider transporteras i ekosystemen. För att göra detta krävs modeller som i sin tur måste baseras på en stor mängd information om biosfären. Ett tidigt steg i en sådan analys måste därför bli att samla och sammanställa information om biosfären. Denna rapport är ett första steg i detta arbete.

I den första delen av denna rapport beskrivs sålunda de terrestra ekosystemen och landklassfördelningen i området tillsammans med en uppskattning av primärproduktionen i olika landekosystem. Primärproduktionen är framräknad för ett modellområde i närheten av Forsmark, baserat på den lokala landklassfördelningen och värden för den totala primärproduktionen (torrvikt). Mängden producerad kol presenteras som $g/m^2$ för respektive landklass.

En viktig del av landekosystemen utgörs av vegetationen som står för primärproduktionen. Den framtida utvecklingen av vegetationen är intressant eftersom produktion och nedbrytning bestämmer hur stor ackumulering av organiskt material som kommer att ske. Detta har givetvis stor betydelse för transporten av radionuklider. Därför beskrivs utvecklingen av vegetationen i den andra delen av rapporten.

Alla förutsägelser om framtida utveckling måste baseras på historisk kunskap i kombination med premisser. Förutsägelsen kommer därför att vara behäftade med fel vars orsak såväl ligger i tolkningen av historien som utformningen av andra premisser för framtida utveckling. Premisserna som gjorts för framtida vegetationens utveckling i denna rapport är simpla vilket betyder att prediktionerna blir grova. För att betona att så är fallet har vi inkluderat en beskrivning av vegetationshistorien. Detta ska ses som ett försök att poängtera skillnaderna mellan en beskrivning av den forna utvecklingen och en förutsägelse av den framtida. Alltså startar beskrivningen av vegetationens utveckling med en beskrivning av historisk utveckling för att sen följas av en prediktion.

Vegetationshistorien visar att utvecklingen huvudsakligen styrs av interaktioner mellan klimatförändringar, strandförskjutning och mänsklig påverkan. Den ordning som träden koloniserar tycks vara enhetlig i området enligt de palynologiska data som är tillgängliga. Träd är snabba kolonisatörer och uppträder tidigt i successionen. Därefter är inslaget av träd relativt stabilt ända tills människan påverkar landskapet. Emellertid finns större förändringar också i relation till klimatförändringar. Under varma och humida förhållanden immigrerar nemorala (värmeälskande) arter och regionala förändringar i landskapselementen kan skönjas. Den största betydelsen har således mänskliga aktiviteter tillsammans med klimatförändringar, medan strandförskjutningens effekter är mer lokala och

snabba. I premisserna för den framtida utvecklingen har klimatförändringar och det mesta av mänsklig påverkan på landskapet uteslutits.

En generaliserad bild över den tänkta framtida utvecklingen av vegetationen i området är presenterad i rapportens tredje del. Det kommer att ske en stark förändring mellan år 3000 och 4000 i och med att stora områden torrläggs på grund av landhöjningen och blir terrestra. Detta innebär sannolikt att nya ackumulationsområden för organiskt material uppstår på sjöbottnar och myrmarker där organiskt material kommer att samlas. Efter år 5000 finns endast mycket små akvatiska områden kvar och endast små mängder kol lämnar området i vattendrag och genom gasavgång. Eftersom rörligheten är större i torrare mark där organiskt material bryts ned och avgår som koldioxid, kommer man att få en förhöjd rörlighet i dessa områden medan man i våta marker får en reduktion. Balansen mellan de olika markerna, och därmed förändringen i kolets rörlighet, är svår att förutsäga. Givetvis påverkas denna utveckling också av omvärldsfaktorer så att till exempel ett varmare klimat kommer att öka rörligheten medan ett kallt och fuktigt reducerar densamma.

# Content

# 1 Introduction

In previous safety assessments the biosphere has been given minor attention and was only briefly described. However, one part of the SAFE-project is to present data on vegetation, ecosystems and land use in the area, in order to make predictions of the circulation of matter (carbon) in the biosphere. In this report we first present a description of present day vegetation and land class distribution in the SFR region together with an estimate of the primary production in different terrestrial communities. The data is intended for the modelling for the safety assessment.

Future development of vegetation is of interest since the transport of components of organic material vary among ecosystems. To make a prediction, however, knowledge of the past development is needed and consequently we have included a description of past development. The area used as reference for this is the Södertörn peninsula south of the SFR. The area was chosen since it is well investigated from many points of view. The description of the past is followed by a prediction of future development of terrestrial vegetation.

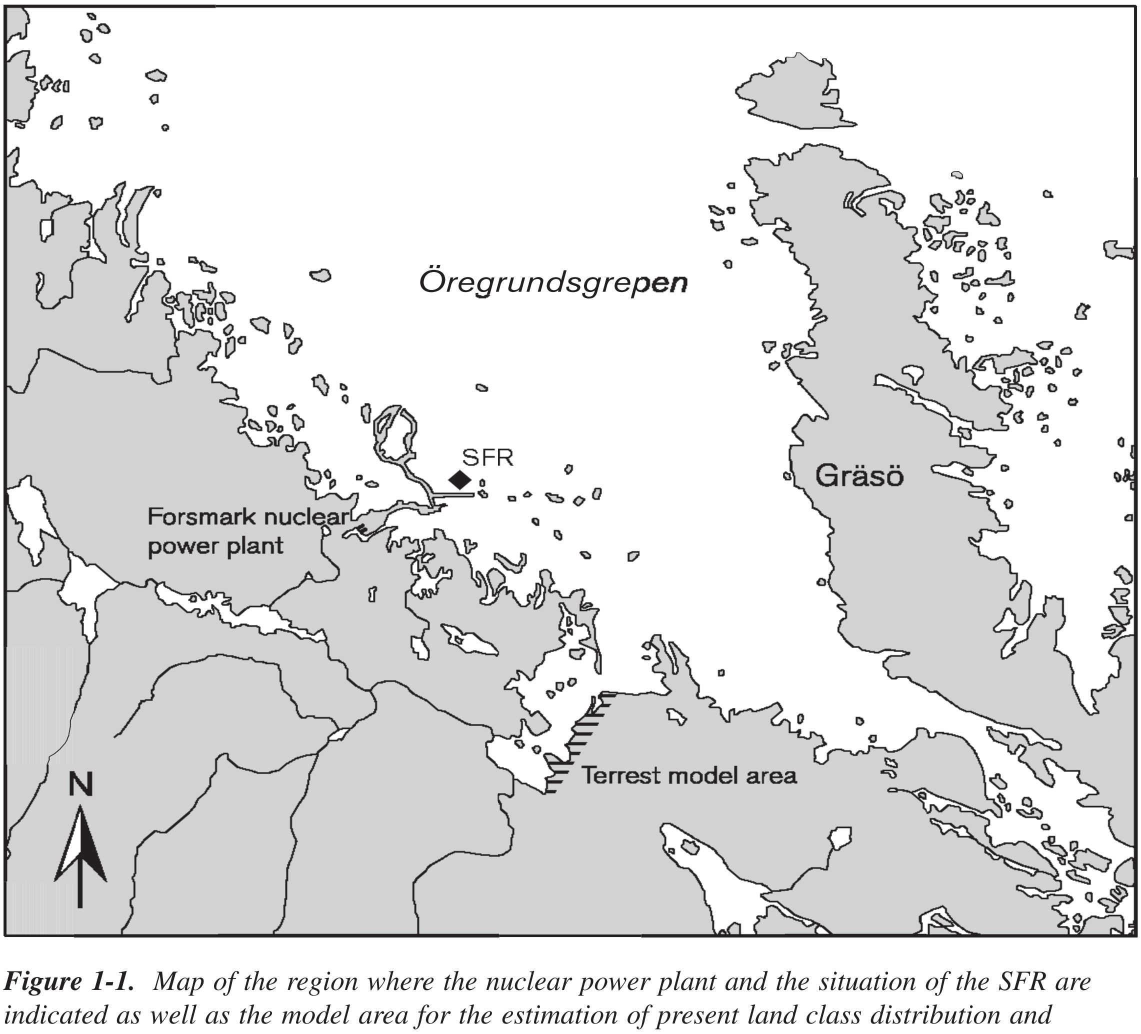


*Figure 1-1. Map of the region where the nuclear power plant and the situation of the SFR are indicated as well as the model area for the estimation of present land class distribution and biological production.*

# 2 The terrestrial environment and production in the SFR area at present

## 2.1 General description

### 2.1.1 Climate

The SFR site is located in the snow climates (Dfb) referring to Köppen classification system /Strahler and Strahler, 1989/. Dfb is the dominating climate zone in Sweden and in north-east Europe. Since the SFR is located at the coast, the Baltic sea has an equalising effect on the climate, meaning that the climate is more humid here than further inland.

**Table 2-1. Climatic characteristics of the SFR area. /Data from Gustafsson et al., 1987; Climates, Lakes and Rivers, 1995; Naturgeografisk regionindelning av Norden, 1984 and Agriculture, 1992/.**

| | |
|---|---|
| Mean annual temperature: | +5.5 °C |
| Mean temperature of the coldest month: | -4°C (February) |
| Mean temperature of the warmest months: | +15°C (July–August) |
| | |
| Mean annual precipitation: | ~650 mm/year |
| Highest measured precipitation: | 80 mm/month (July–August) |
| Mean annual run off: | 200–300 mm |
| Durability of snow cover: | 110 days |
| Average snow depth: | 20 cm |
| | |
| Vegetation period: | 160–180 days (May–November) |
| Frost during growing period: | 10–20 days |
| | |
| Mean sunshine duration/year: | 2000 hours |
| Mean global radiation during June: | 180–190 kWh/$m^2$ |

The Dfb climate zone indicates that the coldest months temperature in average is under 3°C and the warmest month is above 10°C. The precipitation is adequate in all months. Climate data are summarized in Table 2-1 and Figure 2-1.

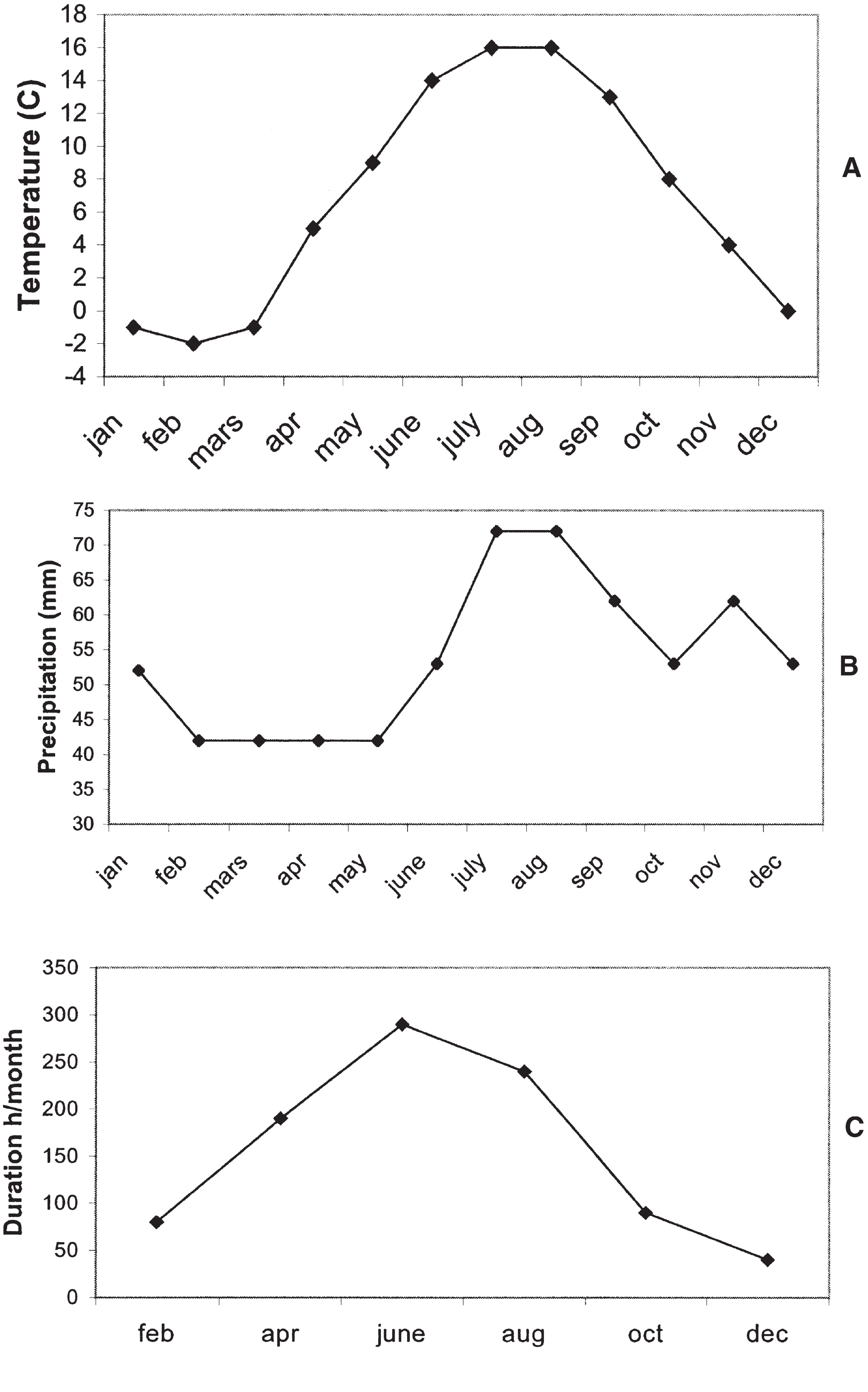


***Figure 2-1.*** *Annual temperature (A), precipitation (B) and solar duration (C) in the SFR region.*

### 2.1.2 Physical geography

Östhammar municipality is situated on the boarder of two different landscapes: "Woodlands south of Limes Norrlandicus" and "Coasts and archipelagos of the Baltic sea". The region is a part of the sub-Cambrian peneplain and quite flat. The soils on the flat peneplain are natural rich with nutrients, but the areas closer to the coast have more exposed bedrock, resulting in less opportunities for agriculture.

The shore displacement in this area is of great scientific interest because of the occurrence of a special type of wetland connected to the land uplift "havsstrandspåverkat topogent kärr" – a fen affected by the topography and the sea shore /Inventering av våtmarker i Uppsala län, 1986/. Geographical data are summarized in Table 2-2.

**Table 2-2. Geographic characteristics of the SFR area. /Data from Naturgeografisk regionindelning av Norden, 1984; Bergman et al., 1996 and Påsse, 1996/.**

| | |
|---|---|
| Altitude: | 0–100 m.a.s.l. |
| Relative relief: | 0–50 metre |
| Dominating soil type: | moraine (40–60%) |
| Most common soil units: | Lithosols and Luvi-cambisols |
| Present relative land uplift: | 5.5 mm/year |

### 2.1.3 Population

Östhammar municipality is quite small and a major part of the inhabitants are living in urban areas /Fakta om Uppsala län, 1995/ (Table 2-3). The most attractive part of the county is the south-west, e.g. Uppsala and Arlanda/Märsta, because of the nearness of urban areas /Översiktsplan, 1991; 1992/ but close to the SFR-region the population is more scarce. On the other hand, the coastal area of Östhammar municipality have many visitors during summer and there are plenty of summer cottages located close to the Baltic sea in the SFR region /Arbete och Fritid, 1993/.

**Table 2-3. Characteristics of the human population in the SFR area. /Data from Strömquist and Pleiborn, 1996/.**

| | | |
|---|---|---|
| Population (tot): | 22 500 | |
| Population in urban areas: | 14 500 | (64%) |
| Population per km$^2$: | 15,5 | |

### 2.1.4 Fauna

The influence from the coast is of great importance for the wild fauna, especially for bird life and wild game. The coastal zonation creates a mosaic of small habitats which in turn give good conditions for high biodiversity. The estimated population size for Roe deer (*Capreolus capreolus*) and Moose (*Alces alces*) in Uppsala county is 4 roe deer/km$^2$ and 0.7 moose/km$^2$ (winter population) /Geography of Plants and Animals, 1996/. None of the four species of large carnivores are now present in this part of Sweden.

The number of breeding bird species is very high in northern Uppland (185 species) and there are about 100 different bird species nesting in the Forsmark region, documented in a 5 x 5 km square /Geography of Plant and Animals, 1996/.

The County Administration has established sanctuaries for birds and seals along the coast. There are 15 sanctuaries in Östhammar municipality and most of them are located far out in the archipelago /Djurskyddsområden i Uppsala län, 1994/.

Mammals frequently occurring in the region:

- Badger (*Meles meles*).
- Beaver (*Castor fiber*).
- Fox (*Vulpes vulpes*).
- Hare (*Lepus sp.*).
- Marten (*Martes martes*).
- Mink (*Mustela vison*).
- Moose (*Alces alces*).
- Roe deer (*Capreolus capreolus*).

## 2.2 SFR region – Vegetation

### 2.2.1 Land classes and vegetation description

In the Forsmark region the landscape is pronouncedly flat, comprising big areas of wetland and coniferous forest on moraine. The calcareous moraine is an important contribution to the rich flora and calcareous influenced Chara-lakes /Bergström et al., 1977; Brunberg and Blomqvist, 1999/. The archipelago is relatively poor with islands compared to a major part of the Stockholm archipelago. The coastline is, including the archipelago, about 400 km, and also on the islands the topography is very flat /Birgersson and Sidenvall, 1996/. The largest island is Gräsö.

The total area of Östhammar municipality is 2790 km$^2$, of which land is 1451 km$^2$ (52%), fresh water is 51 km$^2$ (2%) and the sea is about 1287 km$^2$ (46%). Forests are the dominating land class with ca. 71%, fields 11%, pastures and meadows occupy ca. 3% of the land area and the rest (impediment, urban areas and other land) is ca. 15% /Förstudie Östhammar, slutrapport, 1997/. Compared to the rest of Sweden there are more forests and agricultural land in Östhammar municipality (Figure 2-2).

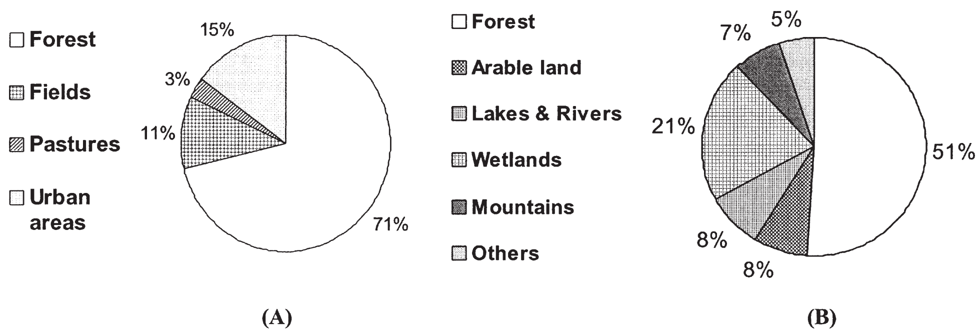


***Figure 2-2.*** *Land class distribution in Östhammar municipality (A) and Sweden (B) /after Birgersson and Sidenvall, 1996/.*

### 2.2.2 Forests

The most common forest type is the 70-year old pine forest, typical of broken terrain in eastern Svealand /The Forest, 1990/. The distribution of forest trees in the region is Pine (*Pinus sylvestris*) 40–60%, Spruce (*Picea abies*) 20–40%, Birch (*Betula pendula*) 10–20%, Oak (*Quercus robur*) <1 and other broad-leaved trees 5–10%. Closer to the coast and the SFR-region the amount of Pine (*Pinus sylvestris*) increases in favour of Spruce (*Picea abies*). The most common undergrowth is the nutrient rich herb type, which is often found in calcareous areas /Miljön i mälarregionen, 1993; Geography of Plants and Animals, 1996/. Some 25–50% of the undergrowth in the SRF-region is of this rich herb type, but it decreases further inland to ca. 15–25%.

In general, the coniferous forests in the area often have a major element of deciduous trees and a shrubby undergrowth. In more wet parts the deciduous trees are dominating together with increasing amount of herbs and grasses. Pine forest is found on thin soils of rocky outcrops of bedrock. The shores are often bordered by Alder (*Alnus glutinosa*) and sometimes Ash (*Fraxinus excelsior*) /Bergström et al., 1977/.

### 2.2.3 Agriculture

The amount of a arable land has decreased over the years. Today Östhammar municipality has ca. 17 200 ha cultivated land and ca. 2 500 ha pastures and meadows. There are 550 farmers and four of them are defined as large companies, i.e. farms with more than 100 cattle units /Birgersson and Sidenvall, 1996/. There are no farms close to the SFR site.

The amount of semi-natural grasslands in the Forsmark region is today ca. 1% of the total land area /Miljön i mälarregionen, 1993/. The forest grazing and grazing on the shore-meadows has almost totally ceased and the landscape is changing character with increased growth in accordance to the successional development. Where grazing still exist the intensity is low /Bergström et al., 1977/.

### 2.2.4 Wetlands

The Forsmark catchment area has a high percent of wetlands compared to Uppland in general. The wetlands is characterized by the calcareous post-glacial clay, which is a prerequisite for the high amount of rich-fens and extreme rich-fens in the area. The Forsmark catchment is dominated by oligotrophic hardwater lakes surrounded by mires. Undergrowth is mostly consisting of different shrub species and peat mosses /Brunberg and Blomqvist, 1999/.

Streams and rivers are rare due to the flat terrain. The river Forsmarksån is the largest water course and drains the big chain of lakes beginning east in the Florarna nature reserve and ends into the Kallrigafjärden /Bergström et al., 1977/. Because of dams and water regulations, the water flow in river Forsmarksån is strongly affected, which has also affected the natural thresholds in the lakes and other parts of the catchments /Brunberg and Blomqvist, 1999/.

There are only a few unexploited lakes in the municipality, since a major part of them are dammed, lowered or turned into cultivated land. The lakes have originated as cut offs from the Baltic Sea, and is successively transported upwards due to the shore level displacement. The buffer capacity is good in ground water and lakes with pH levels >7.1. The lakes are often small and shallow with nutrient poor water and swampy shores containing a lot of Rush (*Schoenoplectus lacustris*), Reed (*Phragmites australis*) and Sedges (*Carex sp.*).

The characteristics and ontogeny of the oligotrophic hardwater lakes in the SFR-region is presented in Brunberg and Blomqvist /1999/.

### 2.2.5 Archipelago and shore meadows

The shore surrounding SFR is a “land uplift shore“, where new terrestrial areas are continuously emerging from the sea because of the shore level displacement. The flat moraine shores outside Forsmark are rich of calcareous rock ground/sediments, giving the islands a vegetation dominated by broad-leaved trees and thickly wooded vegetation. The islands in Kallrigafjärden are of botanical interest containing partly natural coniferous forests rich with deciduous trees and herb-rich undergrowth /Naturvårdsprogram för Uppsala län, 1987/.

The small islands in the outer archipelago have a high degree of exposed bedrock and a vegetation strongly influenced by the guano from the birds, which favours specific lichen species (e.g. *Xanthoria parietina*, *Xanthoria candelaria* and *Ramalina sp.*). The most rocky shores are the outer limit for the green plants. Because of the rough conditions many plant species have a dwarf-shaped morphology compared to less exposed populations. Further inland the vegetation is more diverse, but because of the thin soil and the poor soil units several of the species that occur are drought resistant (e.g. Sea Campion *Silene uniflora*, Biting stonecrop *Sedum acr*e, Woad *Isatis tinctoria*, Scentless mayweed *Matricaria perforata*, Chives *Allium schoenoprasum*). Rocky and sandy shores are often colonised by shrubs like Hawthorn (*Hippophaë rhamnoides*), which is an early colonising species in land uplift areas.

In the outer limit in the archipelago trees often form groups on patches of thicker substrate, e.g. Birch (*Betula pendula*), Aspen (*Populus tremula*), Rowan (*Sorbus aucuparia*), Grey alder (*Alnus incana*). Behind this border of deciduous trees, pine forest develops where outcrops of bedrock occur. Only occasionally the pine forest grows all the way down to the sea shore. Rock pools are a common element on the sea shores and form opportunities for species like Lesser Bulrush (*Typha angustifolia*), Bur reeds (*Sparganium sp.*) and certain bryophytes to exist. The plants and animals change with salinity and nutrition.

## 2.3 Production

### 2.3.1 Production and energy flow in terrestrial communities

Sunlight, carbon dioxide, water and soil nutrients are the resources required for primary production on land. The concentration of $CO_2$ usually plays no significant role in limiting productivity on land, but the quality and quantity of light, the availability of water and nutrients, and temperature all vary dramatically from place to place. Only about 44% of the solar energy is available for use by plants and has the right wavelength suitable for photosynthesis. Active radiation converted to aboveground net primary production differs between terrestrial communities /Webb et al., 1983/. The conifer communities have the highest efficiencies, about 1–3% of the incoming radiation; deciduous forests convert less, about 0.5–1%. Crop plants have the highest potential under ideal conditions and convert from 3–10% of received radiation.

Secondary productivity is defined as the rate of production of new biomass by heterotrophic organisms. The heterotrophic organisms e.g. bacteria, fungi and animals, derive their matter and energy either directly by consuming plants or indirectly from plants by eating other heterotrophs. Since the secondary productivity depends on the primary productivity, there is a positive correlation between the two variables in the communities. It results in a pyramidal structure in which the productivity of plants provides a broad base upon which a smaller productivity of primary consumers depend, with a still smaller productivity of secondary consumers above that /Lindemann, 1942; Elton, 1958/.

Not all the energy that has been assimilated in the system is actually converted to biomass, as a proportion is lost as respiratory heat. The proportion of net primary production that flows along a possible energy pathway is depending on the transfer efficiencies, i.e. consumption efficiency, assimilation efficiency and production efficiency. There are great variations in consumption efficiency in different community systems. Reasonable average figures for consumption efficiency in forests are approximately 5% and in grasslands 25%. About 29% of the net primary production is consumed by the grazer system /Begon et al., 1986/ of which only a small portion is transferred into biomass. A general table of energy flow is presented in Table 2-4.

**Table 2-4. General table for energy flow in a grassland food web. The input is 100% and the percentage value is based on Assimilation = Respiration + Production /after Heal and MacLean, 1975/.**

| | Faeces | Respiration | Production |
|---|---|---|---|
| GRAZER SYSTEM | | | |
| **Herbivore** | | | |
| Invertebrate | 60 | 24 | 16 |
| Vertebrate, ecto | 50 | 45 | 5 |
| Vertebrate, endo | 50 | 49 | 1 |
| **Carnivore** | | | |
| Invertebrate | 20 | 56 | 24 |
| Vertebrate, ecto | 20 | 72 | 8 |
| Vertebrate, endo | 20 | 78 | 2 |
| DECOMPOSER SYSTEM | | | |
| **Microbivore** | 70 | 18 | 12 |
| **Detrivore** | 80 | 12 | 8 |

### 2.3.2 The model area

For energy and carbon modelling on terrestrial communities, it is necessary to have relevant data for production and energy transport in the system. In order to support future modelling we have, by consulting previous studies, estimated the net primary production and the carbon production in four different land classes in the SFR region (see Table 2-5).

To be able to predict the amount and distribution of vegetation and plant communities in the future SFR area, it is necessary to use present conditions in the region. We have chosen a small area (ca. 3.3 km²) south of Forsmark as a model for our calculations and predictions. The area was investigated by Bratt and Karström /1983/ and the report contains a vegetation map of the coastal area, presenting the area of each vegetation type. Only the area closest to the coast, from the sea to 5–10 km inland, have been used for these specific calculations.

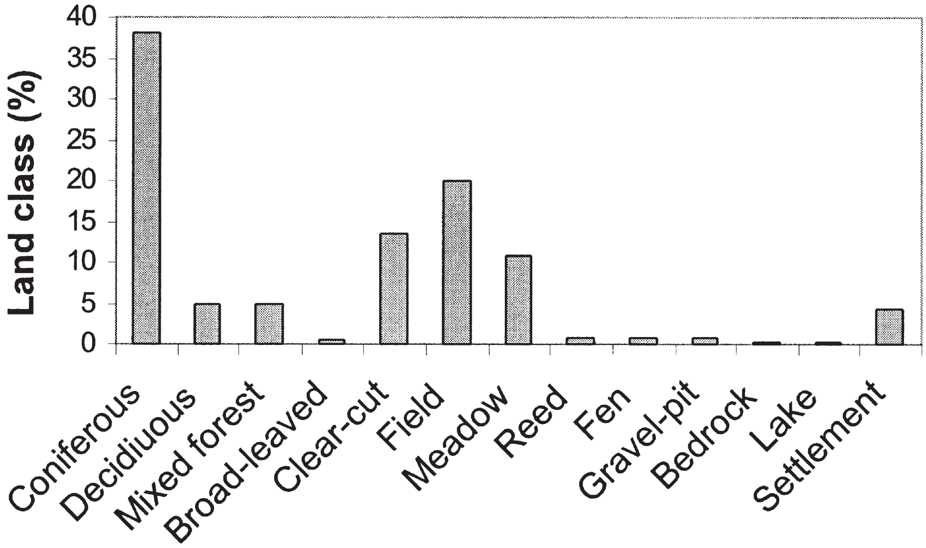


*Figure 2-3. The land class distribution in the model area, after the vegetation map in Bratt and Karström /1983/.*

**Table 2-5. Total production and distribution between land classes of primary production per average km$^2$ and year, in the model area and Sweden, respectively.**

| Land class | Model area (g, dw/m$^2$/yr) | Models area (g, C/m$^2$/yr) | Sweden (g, C/m$^2$/yr) |
|---|---|---|---|
| **Forest land** | | | |
| Productive | 521.0 | 260.5 | 223.7 |
| Impediment (< 1m$^3$/ha) | 5.2 | 2.6 | |
| **Agricultural land** | | | |
| Field | 204.8 | 102.4 | 40.3 |
| Hay meadow | 73.7 | 37.0 | |
| Semi- natural grassland | 29.2 | 15.0 | |
| **Lake and low-productive wetland** (GPP) | 1.1 | 0.2 | 0.1 |
| **Shore meadow** | 5.1 | 2.5 | No data |
| **Total primary production** | **839.0** | **419.5** | **317.0** |

The area has been divided in two different scales: one fine scale, based on different plant communities, and one scale based on land use/land class. The distribution is based on literature research and field observations, representative for the present coastal area of Östhammar municipality and ought to be representative also for vegetation distribution in the closest future.

To estimate the net primary production and carbon production in each land class, the calculations have to be made differently because lack of data. Because of deficiency in the background material, assumptions and generalisations sometimes are necessary to make to be able to reach usable results. To be able to compare the different vegetation types, the land classes is distributed (%) over a one-km$^2$ area, representative for the coastal area (see Figure 2-3).

### 2.3.3 Production in the model area

#### *Forests*

The calculations of net primary production in forests often includes only wood production, because of the economical interest in forestry. Investigations to estimate the distribution of production in Swedish forest had been made by Eriksson /1991/. Net primary production in the forested land is in this paper calculated by using the average ratio between sk/ha (stem wood) and the total production. According to Eriksson /1991/ is 25% of the net primary production stem wood (Table 2-6).

The volume of total growing timber/ha of all tree species in the SFR area is ca. 120–140 $m^3$ sk in this region and the average annual growth is 4–5 $m^3$ sk/ha. Some 95% of the forest is productive and 5% impediment /The Forest, 1990/.

Site quality is an expression of the fertility of the forest land, which is influenced by the geographical location of the sites, climate, humidity, and species. These parameters are translated into a quality classification expressed as wood production ($m^3$) per hectare and year during the rotation period (100 years for Pine *Pinus sylvestris* and Spruce *Picea abies* and 50 year for Birch *Betula spp*). In the Forsmark area the site quality (potential production) is ca. 6–7 $m^3$ sk/ha/year /The Forest, 1990/. These figures represent the forest industry and do no not concern the less fertile forest areas like the coastal pine forest on outcrops of bedrock which has about 2–3 $m^3$ sk/ha/year /The Forest, 1990/.

The average bulk density of wood in Sweden has been estimated to be 0.42 ton d.w. per $m^3$ stem wood and the carbon content of wood is ca. 50% /Eriksson, 1991/.

The estimated net primary production in the forest land in the SFR region is 521 tonnes (d.w.)/$km^2$/year. The forest impediment (an average of 5% of the forest land in the region) produces ca. 5.1 tonnes (d.w.)/$km^2$/year, see Table 2-6.

**Table 2-6. Distribution of production in a Swedish forest land /Eriksson, 1991/.**

| Production | % |
|---|---|
| Stem wood | 25 |
| Branches | 22 |
| Fine litter | 4 |
| Stumps and roots >2 mm | 11 |
| Roots <2 mm | 18 |
| Remaining vegetation incl. roots | 20 |

The forest produces 3–5 $m^3$ sk/ha and year. We have chosen 5 $m^3$/ha or 500 $m^3$/$km^2$ to represent the production in the area. According to the vegetation map, the model area consists of 62% forest land (including deciduous and clear-cut wood land). An average square kilometre in the model area therefore produces about 500 x 0.62 = 310 $m^3$ sk per year. Since the stem wood is 25% of the production, this figure must be multiplied with 4 to reach the total amount of net primary production, = 1240 $m^3$ biomass. The weight of one cubic metre forest is 0.42 tonnes (d.w.), giving the model area = 1240 x 0.42 = 521 tonnes/$km^2$. The carbon content in all types of vegetation is about 50%, which give a production of 260.5 tonnes carbon/$km^2$ and year in the forest land.

### *Cultivated land – arable land*

Standard yields are calculated every year for all crops covered by the objective yield surveys /Statisitiska meddelanden, 1997/. Sweden is divided into 104 yield survey districts and in each district the conditions are comparable. In Table 2-7 the yields for Forsmark region /Statistiska meddelanden, 1997, district 0322/ are presented in kg/ha.

**Table 2-7. Standard yields (kg/ha) for yield district 0322 in 1997 (SCB).**

| | |
|---|---|
| Ley for hay or silage | 7567 |
| Oats | 3016 |
| Barley | 3150 |
| Rye | – |
| Spring wheat | – |
| Winter wheat | 3669 |

By using the standard yields in Table 2-7 we calculated the net primary productions (nPP) for respective oats, barley and winter wheat. The nPP for oats in the model area was 43.5 tonnes d.w. per average km$^2$/yr, barley 144.3, winter wheat 5.5 and unspecified (mixed crops) 11,5 tonnes d.w. per average km$^2$/yr, see Table 2-5 for total field production in the model area.

To calculate the nPP in the cultivated areas, we have used figures for yield, threshing loss, straw yield and added an estimated figure for root production (see example oats below) /Ländell, unpubl. SCB; Eriksson, 1991/. Oats: 3016 (kg/ha/yr standard yield) x 1.05 (threshing loss) x 1.4 (straw yield) + (3016 x 1.05 (seed yield)) x 1.43 (root production) = 10869 kg/ha/yr = 43478 kg/km$^2$/yr total primary production of oats. Barley and Winter wheat productions was calculated with the same procedure.

### *Cultivated land – Pasture and meadow*

In the model area the pasture/meadow land is represented by two land types, hay-meadow and semi-natural grassland. These two land types represent 10.9% of the total model area. We have estimated that 50% of the land is hay-meadow and 50% is semi-natural grassland. 5.45 % of the model area has a yield of 7567 kg (d.w.)/ha/year and the other 5.45% has a yield of 3000 kg (d.w.)/ha/year, which gives a total production in cultivated land – pasture and meadow per square kilometre of ca. 103 000 kg (d.w.)/year or 51 500 kg C/km$^2$/year, see Table 2-5.

We estimated the amount of hay-meadow and semi-natural grassland to 5.45% respectively of the total area (10.9%). The production in the hay-meadow land was calculated to 5.45 x 7567 (Table 2-5) x 1.25 (80% of above ground production is usable – yield) x 1.43 (root production) = 73 717 kg (d.w.)/km$^2$/year. The production in the semi-natural grassland was calculated to 5.45 x 3000 /Ekstam and Forshed, 1996/ x 1.25 (80% of above ground production is usable – yield) x 1.43 (root production) = 29 226 kg (d.w.)/km$^2$/year = total production 102 943 kg (d.w.)/km$^2$/year.

### *Lakes and low productive wetland*

The total organic carbon gained through gross primary production within the lakes and organic carbon entering in runoff from the catchment area roughly equals the organic carbon lost through sedimentation, runoff to the sea and decomposition by plant, microbial and animal respiration /Eriksson, 1991/. Estimated gross primary production in lakes ranges for different trophic classes. In a mesothrophic lake the GPP varies between 0.3–0.6 ton C $ha^{-1}$ x $year^{1}$. In an average square kilometre in the model area the total production is 100 kg carbon/year, see Table 2-5. The gross primary production in mesothrophic lakes is 0.3–0.6 ton C/ha/year /Eriksson, 1991/. The estimated lake area per $km^2$ in the model area is 2000 $m^2$ (1/5 ha). We have chosen to use an average figure representing the area, 0.5 ton C ha/year; 0.5 ton C/5 = 100 kg C/$km^2$/year.

### *High productive wetland*

We have not been able to locate any data on the production in high productive wetland. Since this land class is very small in the SFR area the lack of data will have very little importance for the total production in the model area.

### *Shore meadow*

The above ground biomass production in a shore meadow ecosystem differs depending on what species that is a part of the local plant community and the abiotic conditions during the year. According to Tyler /1971/ a plant community system in the Stockholm archipelago produces between 160–320 g/$m^2$ depending on the site specific conditions.

Most of the figures used by Tyler /1971/ are based on a Saltmarsh rush (*Juncus gerardi*) ecosystem. The investigated site had been grazed 20 years earlier but was at the time of investigation left untouched. The above ground litter remaining from previous growing seasons in the spring is amounted to 500–600 g/$m^2$. In late autumn only 300–350 g/$m^2$ remains, the rest is decomposed.

In order to present production values for the shore meadow in the model area, we have calculated the average shore width to 10 m and the coastline to 1.5 km/$km^2$ (1.5% of the total model area). By using these figures the production in the shore meadow area is calculated to 5143 kg (d.w.) /$km^2$/year or 2570 kg C/$km^2$/year, see Table 2-5.

According to Tyler /1971/ the production in a shore meadow is between 160–320 g/$m^2$. We have chosen an average to represent the model area production =240 g/$m^2$. The coast line is calculated to 1.5 km and the breadth to 10 metre. Some 30% of the primary production is under ground production /Eriksson, 1991/. This gives a total primary production of 240 x 15.000 + 1543 = 5143 kg (d.w.) /$km^2$/year.

### *Conclusion*

The land class distribution in the SFR region is, as expected, different from the rest of Sweden, e.g. more forest and less agriculture, which is a result of the low productive areas along the coast. In spite of the low productive areas the primary production in the model area (419 ton C/$km^2$/yr) is higher than in the rest of Sweden (317 ton C/$km^2$/yr)

/calculated from Eriksson, 1991/. One explanation is that the model area does not have any vast impediment or low productive areas like the Swedish mountains. The values for the production in the SFR area seem reasonable considering the vegetation description of the region and in relation to the mean values for total primary production in Sweden.

All data and calculations made in this report are presented as basis for modelling in the SFR area. Still there are many uncertainties concerning production in terrestrial environments and very few data from relevant research and production in different terrestrial habitats have been found. In other words, the values for a specific area like SFR will be strongly generalised.

This report only present data for primary production in different habitats. For a complete terrestrial model secondary production in different communities must be considered.

The future production of the SFR area is hard to predict, since what type of land use that will be the dominating is the decisive factor.

# 3 The development of terrestrial vegetation

## 3.1 Historic changes in general

The change in flora and vegetation in the archipelago occurs on several spatial and temporal scales. First, one may discern *long term change* including regional changes in the species pool due to migration, to altered environmental conditions, such as climatic change, permitting new species to invade but excluding others (section 3.2). Second, on a shorter time scale the ongoing colonisation from the mainland to the islands in the archipelago creates a continuous regional *succession* (section 3.3) which accelerates in the first stages of the development of a particular island. Later, in forested stages, the succession is slowed down if the area is not disturbed. In addition there is also succession occurring within a particular island mainly due to the increment of land in relation to shore displacement. Third, superimposed on this "natural" succession there is a change driven by *human management*. The archipelago has, during periods, been intensely managed and terrestrial areas have bee utilised for cattle-breeding and farming. For haymaking, the land was kept open and trees and bushes were cut. This counteracted the "natural" succession but also created living space for other species connected to managed ecosystems.

Thus, the flora and vegetation of today is the result of a mixture of processes acting in different temporal and spatial scales. It is difficult to separate these processes, as long term studies and experiments are scarce. Therefore, detailed interpretations of the past processes are not available and thus predictions concerning future development become coarse.

## 3.2 Long term changes

### 3.2.1 Reference area for past changes

Södertörn, a peninsula situated ca 60 km south east of Stockholm, is in particular a well investigated research area for pollen analysis and shore displacement as well as deglaciation chronology /e.g. Granlund, 1928; Florin, 1944; Brunnberg, 1988; Miller, 1982; Strömberg, 1989; Åkerlund, 1996/. The area has therefore been used as a model area for the SFR region. If you consider the Stockholm archipelago as a homogenous region, with almost the same abiotic development since the latest glacial, the Södertörn peninsula will quite well represent the vegetation development in the SFR region.

### 3.2.2 Post glacial climate and shore displacement

The post-glacial shore level displacement in the Baltic sea area is well investigated /e.g. Påsse, 1996/ in various disciplines, archaeology /e.g. Granlund, 1928; Florin, 1944; Åkerlund, 1996/, and physical geography /e.g. Åse, 1970/. The ice retreated from the region for about 10 000 years ago (Figure 3-1) when the highest areas emerged from the Yoldia Sea. One of the first islets that rose above sea level in this part of the region was the summit Tornberget (110 m.a.s.l.) on the Södertörn peninsula emerging through the water surface at about 8800 BP (Before Present).

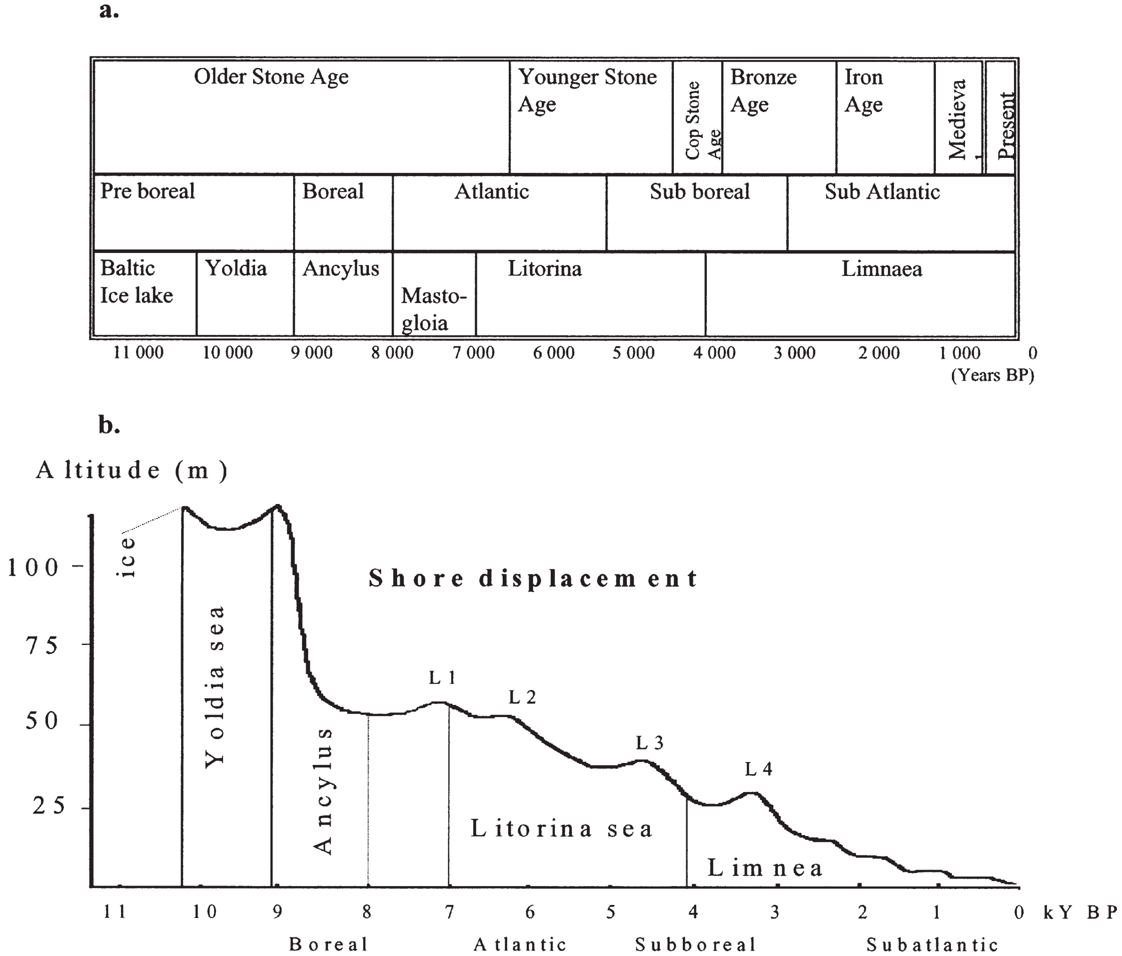


***Figure 3-1.*** ***a.*** *History stages (1), Climatic stages (2) and Baltic sea stages (3) in the Stockholm region /after Berglund et al., 1996/.* ***b.*** *Generalised shore displacement curve and Baltic Sea stages in the Stockholm region /redrawn after Risberg et al., 1991/. Altidude in meters, kY BP denotes thousands of years Before Present.*

After the retreat of the latest glacial ice cover, the Baltic Sea water has changed between saline conditions and fresh and further between cold and warm respectively /Westman et al., 1999/, which has also affected the development of terrestrial vegetation. From the end of the Yoldia period the shore displacement went fast and at the end of the Ancylus stage about 8000 BP the shore line lay about 60 m.a.s.l. The climate was still boreal with dry summers. Later between 8000 and 7000 BP the climate became more maritime (Atlantic period). The climatic optimum of the warm period was at ca. 6000 BP, when the Litorina transgression reached its highest level in the Stockholm region /Miller and Hedin, 1988/. This is called the Litorina limit (L1), which in the archipelago of Stockholm reached ca. 57 m.a.s.l. ca 7000 BP (Figure 3-1).

The largest terrestrial area increment of the Södertörn peninsula occurred during the Litorina period from 7000 to 3100 BP and large land areas were exposed in the Sörmland and the Uppland archipelago. Since that time a regressive trend has been in progress in the region, interrupted at some times by trangressions e.g L2, L3 and L4 in Figure 3-1b /Miller and Hedin, 1988/. After the post glacial warm period (i.e. the Atlantic period) came to an end, the eustatic rise of the Baltic Sea decreased. The land uplift proceeded after the regression and kept on during the following Limnea period /Åkerlund, 1996/. For more detailed information see Risberg et al. /1991/.

The climate during the Litorina period was dominated by the post glacial warmth period. Around 5000 BP the climatic condition changed from Atlantic to Sub-boreal conditions i.e. became colder /Miller and Hedin, 1988/.

According to several paleobotanical studies there was an important climatic change 2500 BP, which is traced in the change of vegetation. The climate gets dryer and a relatively short period of warmer climate from about 1500 to 800 BP is noticeable /Westman et al., 1999/. A small transgression isolate Lake Mälaren from the Baltic sea /Berglund et al., 1996/.

The first documented traces of man in Södertörn was earlier dated to ca. 7000 BP but has recently been backdated to 9000 BP at altitudes around 80 m.a.s.l. /Schnell, 1930; Nordström and Ferenius, 1984; Olsson and Åkerlund, 1987/. At that time the Södertörn area was a small islet in the outer archipelago of the Ancylus Lake /Åkerlund, 1996/. The intensity of the human impact on the environment and the vegetation increased as the settlements moved according to the shore level displacement /Risberg et al., 1991/.

### 3.2.3 The post-glacial vegetation development in the coastal area

To be able to trace the previous vegetation development it is necessary to find evidence of earlier existing plant species. The most common approach is to search for pollen in the soil layers. By using the stratigraphic information from the soil samples, many details concerning climate, water temperature and salinity can be traced, which may give a good picture of the conditions for earlier vegetation establishment. Pollen diagrams have been made from several study sites in Södertörn, which give examples of different plant community structures from the same region and time period /e.g. Florin, 1957; 1958; Miller and Hedin, 1988; Risberg and Karlsson, 1989/.

#### *10000 BP to 7500 BP*

According to Risberg and Karlsson /1989/ had the area nowadays called Södertörn 8800 BP only vegetation on Tornberget. All pollen that is accumulated in the sediment ought therefore to be transported a long distance or is secondarily dispersed. Pollen diagrams from this period show that the vegetation around one of the localities, the lake Ådran, in the early parts of the period (ca 10000 to 9500 BP) was dominated by pioneer species, especially trees. The most abundant species were Birch (*Betula spp*) with 45% and Pine (*Pinus sylvestris*) 45%, later (9500–9000 BP) also with a contribution of Hazel (*Corylus avellana*) 5% and some Elm (*Ulmus glabra*) and Aspen (*Populus tremula*). Later in the warmer parts of period there was an expansion of termophilus broad-leaved trees, e.g. Oaks (*Quercus spp*), Elm (*Ulmus glabra*) and Ash (*Fraxinus excelsior*) /Miller and Hedin, 1988/. In the time between the Boreal and Atlantic periods (ca 8000 BP) *Tilia* immigrates to the area around lake Ådran /Risberg and Karlsson, 1989/. The colonisation pattern differ between sites and according to Persson /1981/ the first traces of Lime (*Tilia cordata*) in another sampling site of the area, Frillingsmossen, occurs more than 1000 years later, ca. 6600 BP.

Of the total amount of pollen from herbs and bushes found at lake Ådran in this period, Willows (*Salix spp*) was represented with ca. 2%, Grasses (*Poaceae*) 5%, Mugworts (*Artemisia spp*) 3%, Goosefoots (*Chenopodiaceae*) 2%. Also pollen from Rushes and sedges (*Cyperaceae*), Sorrels (*Rumex spp*) Meadow rues, (*Thalictrum spp*) and Rose-family (*Rosaceae*) occurred in the samples. The pollen concentration from all the cores from this period was very low, which indicates a generally sparse vegetation in the region /Risberg and Karlsson, 1989/.

In some samples there are local concentrations of certain species e.g. Pine (*Pinus sylvestris*) Birch (*Betula sp*p), and Hazel (*Corylus avellana*), which indicates a local variation in plant community structure. A bit further up in the core, as the conditions for establishment changes, a difference in the plant community is noticed; the occurrence of Alder (*Alnus glutinosa*) and Oak (*Quercus spp*) increases, together with species of the Heather family (*Ericaceae*) and Grasses (*Poaceae*).

### *7500 – 5500 BP*

The archipelago of the area became extensive during Litorina period. Pollen samples from that time suggests the landscape to be mosaic and changing between areas with a high frequency of Scotch Pine (*Pinus sylvestris*) and others with a high frequency of deciduous trees depending on where in the archipelago, outer or inner, the sample is taken /Florin, 1957; 1958/. As the bays and lagoons were cut off, the amount of Pine (*Pinus sylvestris*) pollen in the sediment decrease. The most plausible explanation for this is that the transportation into the area is prevented due to the land up-lift and the water dispersal of Pine (*Pinus sylvestris*) pollen ceases /Florin 1957; 1958/.

The plant geographical zonation in the archipelago of Sörmland at this period was very similar to the zonation in northern archipelago of Stockholm today with an outer treeless zone. Inside this a forested region dominated by Birch (*Betula spp*), and to a lesser degree Aspen (*Populus tremula*) and Alder (*Alnus glutinosa*). Close to the main land larger islands occur, with areas of high altitude dominated by Pine forest and deciduous trees in the depressions. Along the coast deciduous forests with a strong contribution of Alder (*Alnus glutinosa*) was frequently found.

During the relatively warm Atlantic period (9500–5500 BP) the amount of plant species increases in the region. The thermophilous broad-leaved trees, especially the amount of pollen from Elm (*Ulmus glabra*) and Lime (*Tilia cordata*), increased drastically in the end of the period when the greatest amount of deciduous trees through the postglacial history is to be found /Risberg and Karlsson, 1989/. Only few signs of human influences can be traced from the period.

### *5500 – 2500 BP*

During the sub-boreal period (5500–2500 BP) the amount of deciduous trees decline, probably due to the change towards colder climate. A declining trend of for example Elm *(Ulmus glabra*) is registered ca. 4500 BP. The first pollen of Spruce (*Picea abies*) occurs early in the period (probably as a result of long-dispersed pollen). Later also traces of scattered stands of Spruce (*Picea abie*s) are found in the earlier sub-boreal time (4500–3800) BP. Traces of Beech (*Fagus sylvatica*) pollen also occur around 5000 BP, probably transported from more southern parts of Sweden. The amount of pollen of nemoral (thermophilous) trees (*Quercus*, *Ulmus*, *Tilia* and *Fraxinus*) continues to be relatively high in spite of the abundance of Pine (*Pinus sylvestris*) pollen (4600 BP) and even though there is a change in plant community structure, broad-leaved trees were common in the forests /Miller and Hedin; 1988/. A high amount of Hazel (*Corylus avellana*) may partly be due to human activity as hazelnuts were an important part of the food supply /Miller and Hedin, 1988/.

Easily dispersed fern spores are rather abundantly represented in some clay layers in the Stockholm area during this time, e.g. Male fern (*Dryopteris filix-mas*), Lady fern (*Athyrium filix-femina*) and Polypody (*Polypodium vulgar*e), all of which are common on tree-less islands. The pollen spectra from clay-layers also contains characteristic species like Goose foots (*Chenopodiaceae*), Sorrels (*Rumex spp*), Plantains (*Plantago spp*) and Mugworts (*Artemisia spp*) /Fries, 1962/. The amount of pollen from species favoured by the warm climate continues to decrease further as the suboreal period continues but some nemoral (termophilus) relicts are still left in present day from this post-glacial period. The development is not always unidirectional and data from several pollen diagrams show an increase of Lime (*Tilia cordata*) in the Stockholm area during in the middle sub-boreal 3500–3300 BP /Urve Miller manuscript; Miller and Hedin, 1988/.

During the period the amount of Grass (*Poaceae*) pollen continuously increases, which may indicate human activities in terms of creation of man-made of open landscapes, favouring dispersal and recruitment of grasses. Species indicating antropogenic activities becomes more easily traced as the period proceeeds. According to Risberg and Karlsson /1989/ there is a significant increase in the amount of Grasses (*Poacea*e), which indicates a more open landscape, but no direct archeological evidence of human management is found. The human impact, however, in the region presumably increased and local clearences occurred in the end of the period /Berglund et al., 1996/. Trees used as animal food and construction of tools also became more common. Local deforestation is probably common, exhibited in the decrease of tree pollen.

### 2500 BP to present

The most obvious trace from this slightly colder climate period is that the oak-mixed forests in the Stockholm archipelago declined in favour of the more tolerant Spruce (*Picea abies*).

This is also the time when the cultural influences of the landscape became more prominent ca. 2000 BP /Fries, 1962/ and both factors may contribute to the reduction of Oak forests. Also hazel stands were decimated at that time. Probably more and more of the ground was used, as meadows, pastures and crop fields and, as the trees were cut down, a gradual increase of pollen of wild grass is seen in the diagrams. Not every study, however, can show a noticeable change in the pollen diagram from that time /Fries, 1962/. Long-distance transported pollen becomes more and more prominent in the local pollen flora, maybe as a result of increased import due to the opening of the landscape. A strong expansion of Spruce (*Picea abies*) starts in the beginning of the sub-atlantic period /Miller and Hedin, 1988/. During this period the productivity of vegetation increases as well as the amount of new species. Natural overgrowing of fens and other wetlands can be traced in the amount of Birch (*Betula spp*) pollen from some islands, but this is a very local increase /Karlsson, 1998/.

According to Hammar /1989/ the human impact on the environment increases around 1200 BP and as the landscape became more open and the amount of cultivated areas increased, the plant community structure changes. Species connected with human impact and open landscape becomes well represented in many pollen samples /Hammar, 1989/. All land classes connected with human activities gets more and more common during this period, e.g. cultivated land, ruderal communities, meadows and especially dry pastures. The exploitation of the cultural landscape continued through the Vendel period, the Viking period and the early medieval time. Traces of cultivation are more rare in the outer archipelago, maybe due to both smaller areas of suitable soil composition and transport difficulties. Although you see some traces of cultural plant species in the samples, e.g. Ribwort plantain (*Plantago lanceolat*a), Hoary plantain (*Plantago media*), White clover (*Trifolium repens*), Bellflowers (*Campanula spp*), Knapweeds (*Centaurea spp*) most of the species found in the samples are plant species favoured by grazing /Karlsson, 1998/. An increase in the amount of Birch (*Betula spp*) may indicate an overgrowing period after human activities /Karlsson, 1998/.

### 3.2.4 Sources of error

There are several sources of error involved in interpreting historic data. Risberg and Karlsson /1989/ and Risberg et al. /1991/ are discussing important factors that may give a wrong picture of the real plant community structure and a few will be mentioned.

- a very high sedimentation rate, diluting the amount of pollen makes a species under-represented. Resedimentation is another process that may dilute the amount of pollen.
- the potential for pollen from different species to be conserved in the sediment vary.
- the amount of pollen found in the environment does not reflect the actual vegetation structure in an area, since plant species produce different amounts of pollen with different dispersal capacity. In general species with pollen dispersed by wind produces a higher amount of pollen than insect pollinated species. One example of a species that produce great amounts of pollen and also is efficiently dispersed by water/wind is Scotch Pine (*Pinus sylvatica*). Since no corrections have been made in most pollen diagrams, some species, like e.g. pine may be over-represented.
- the differences seen in the pollen samples do not reflect a local or regional change in the plant community structure but instead variation in topography, pollen transport, human impact, natural succession or local climate /Karlsson, 1998/. Thus, it is difficult to make general conclusions of the vegetation structure in an area, as samples taken only reflects the very spot from where they are taken /Brunnberg et al., 1985/.

Some of the data, especially the first occurrence of Spruce (*Picea abies*), are contradictory depending on source. Where differences in the data sometimes are more than 2000 years /e.g. Miller and Hedin, 1988/. One explanation may be that the pollen is secondarily dispersed and have their origin in another part of Sweden, than the samples were taken. Recently there have been discussions on the exact time and direction for the invasion of Spruce (*Picea abies*), where new material (e.g. still living specimens have been $C^{14}$ dated to an age of 6000 years) seems to suggest an earlier immigration /Segerström, 1998, pers. com/.

### 3.2.5 Conclusion

The vegetation history of the Stockholm archipelago is an interaction between changes in climate, shore displacement, local vegetation development and human activities. The order of arrival of the forest trees are very much the same all over the Stockholm archipelago. Pine (*Pinus sylvatica*), Birch (*Betula spp*) and Hazel (*Corylus avellana*) were the first to colonise the skerries that emerged from the sea, some 10 000 BP (Figure 3-2). A few hundred years later Elm (*Ulmus glabra*) and Oak (*Quercus robur*) reached the region. Both Lime (*Tilia cordata*) and Ash (*Fraxinus excelsior*) were later to immigrate. Spruce (*Picea abies*) has its expansion much later, about 2 500 BP. The early Holocene period area was totally dominated by Birch (*Betula spp*) and Scotch Pine (*Pinus sylvestris*), while the middle of Holocene is characterised by the expansion of nemoral forest trees.

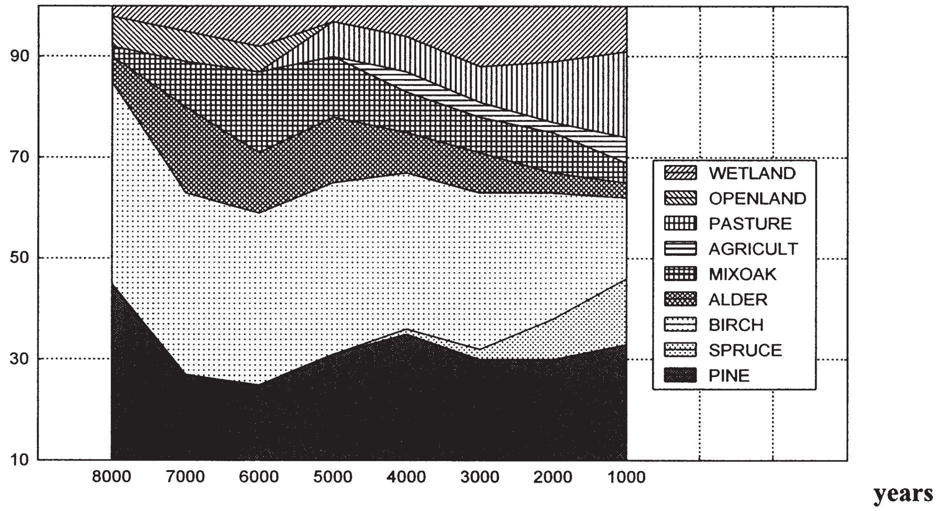


***Figure 3-2.*** *Land class distribution (in %), named after the most dominant tree species, in the Stockholm archipelago (esp. Södertörn peninsula) during the last 8000 years, based on literature (see references).*

The palynological data often show great similarity concerning the vegetation development on the emerged islands, but differences do occur. When compiling data from Karlsson /1998/ from four closely situated islands, we found many differences in plant communities during the last 2000 years. In spite of the relative nearness between the island this indicated that there are different local conditions, e.g. micro-climate or land use. Generalisations may therefore sometimes be misleading. The relative frequency among trees, shrubs and herbs (Figure 3-3), indicate that the trees are fast colonisers and occur early in the succession. After some 1000 years the distribution is quite stable and stays indifferent until human activities began, ca. 3000 BP. This indicates that the effect of human impact on vegetation type is very important; probably much more important than both natural succession and shore displacement.

As the new land emerges new species can establish and the primary succession continues. This means that the land class distribution in the coastal region do not changes even though the local spatial patterns are continuously changing.

Differences in plant community structure can be seen according to climate change. When the climate got warmer and more humid, nemoral (termophilous) species immigrated, and the distribution of land classes changed on a regional scale.

Concerning short term changes there are three factors that mainly drive the change. Human management, colonisation from the main land and succession in relation to shore displacement. The most important factors changing the environment and plant community is human impact while shore displacement may affect locally and on a short time scale.

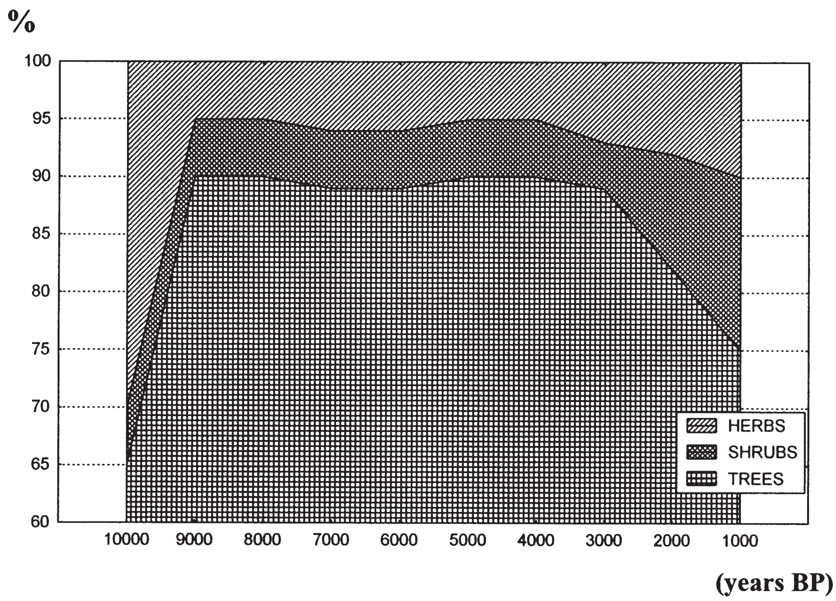


***Figure 3-3.*** *Holocene pollen diagram showing the relative amount of trees, shrubs and herbs in the Stockholm archipelago /after Berglund et al., 1996/.*

## 3.3 Succession

### 3.3.1 Regional succession

The number of species on islands decreases as one moves from the main land outwards through the archipelago (Figure 3-4). There are several reasons for this. The amount of species on a particular area is a function of dispersal ability and the potential to establish and persist.

Some species possess efficient dispersal characteristics others are poor dispersers. The latter will be out-distanced in the colonisation race but may slowly catch up. Even though a species may reach an island it may not be able to establish. There may be many reasons for this e.g. the abiotic environment prevents it to, others may outcompete it, the biotic environment is not yet at hand. Several plant species are thought to be lacking in the outer archipelago because no forests are found on the islands, i.e. the forests have to be there first. The flora of the archipelago of today is somewhat special depending on the relatively high degree of deciduous trees where Alder (*Alnus glutinosa*) is a key species producing litter rich in nitrogen. The flora of organic soils formed may include more demanding plant species such as Ramsons (*Allium ursinum*), Wood barley (*Hordelymus europaeus*) and others. Frequently bushes or small trees are mixed in e.g. Guelder rose (*Viburnum opulus*), Mountain currant (*Ribes alpinum*) and Yew (*Taxus baccata*).

In small populations, such as in small islands, the risk for extinction is increased. Thus, there is a faster turnover of populations of many species in the outer archipelago which may reduce the diversity. Small islands, dominant in the outer archipelago, are more difficult targets for seeds to hit, further they carry smaller populations inferring increased risks of extinction, and are thus expected to contain fewer species. This is obvious from the graph in Figure 3-4. As the area of islands grow large they will approach the same level of species number as that of the mainland.

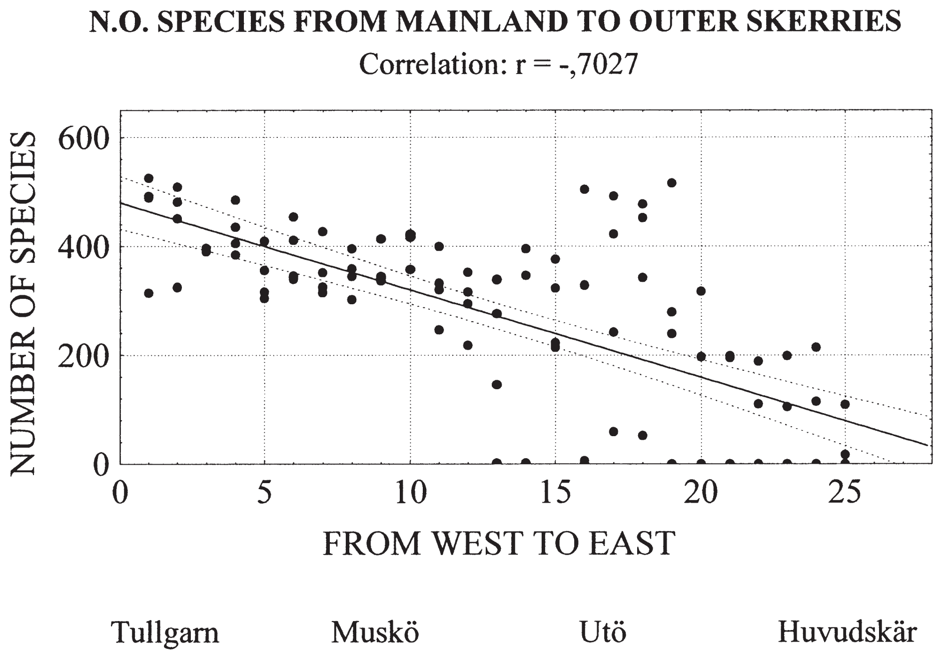


***Figure 3-4.*** *The number of species of vascular plants in an east west gradient from the mainland to the outermost islands in the southern part of the Stockholm archipelago, A significant reduction in the species pool from mainland to outer skerries can be seen.*

### 3.3.2 Local succession

Post-glacial isostatic land uplift affects the entire coastline of the northern Baltic sea. The most important abiotic conditions, affecting the vegetation community on the sea shore, is the soil, the degree of exposure and the salinity /Jerling, 1999/. The soil type is strongly connected to the degree of exposure, where high 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 colonised by vegetation /Ericson and Wallentinus, 1979/. Because of the flooding frequency and salt spray intensity, the vegetation composition does not change independently from the land uplift rate until many years after emergence of sites from the sea /Cramer, 1986/.

A long time after the emergence of an island the plants that have colonised runs the risk of being submerged as the variation in sea level is more than a meter annually. Thus, the first colonisers must be tolerant to inundation. In crevices and depressions debris may accumulate together with litter from established organisms. This material facilitates colonisation by new species. As the risk for inundation decreases lichens and mosses establish and build up to organic soils. These are mixed by bird faeces and together the formed soils are favourable for a number of colonising plants.

The loose material are further built up by litter from the new species. Some species like Alder (*Alnus glutinosa*) and Hawthorn (*Hippophaë rhamnoides*) have a litter which is rich in nitrogen and this facilitates the establishment of many species. From bushes and tress a varied light environment is created and new habitats are created. In this way, the flora and vegetation is steadily changing but with a relatively high degree of determinism. This results in patterns related to the age, size and physical properties of islands.

The vegetation zonations of the primary succession of the Baltic sea shore is not only a response to changes in environment due to land uplift, but also a successional trend reflecting micro climate /Lindroth, 1965/, edaphical and topographical heterogeneity /Olson, 1958/ or salt spray gradients /Oosting, 1954/. The degree of wave exposure at the site may also influence the plant establishment. Also human activities may disturb the sequence /Cramer, 1986/. After primary succession the communities internal dynamic is the main structural process in the sea shore system.

In an undisturbed coastline the winter ice often leaves traces of ice erosion. Alder (*Aldus glutinosa*) is a species that seldom establish in closed vegetation and relies on gaps in the terrain. Along the coastline a fringe of Alder (*Alnus glutinosa*) is common as a result of establishment in the ice eroded scar.

### 3.3.3 The SFR area

The plant community may be altered both due to the catastrophic destruction of entire vegetation belts or due to favourable establishment conditions for a number of species. Vascular plant populations have been shown to react strongly to short time change in this environment /Ericson 1980; 1981/. In general, plants with a rapid life-cycle, e.g. annual plants, establish more easily in disturbed environments like sites close to the waterline. It may be possible for the annual plant to establish and flower before the water level raise during late spring /Torstensson, 1986/. For perennial plants with both vegetative and generative dispersal, the generative form of establishment often is more successful than the vegetative in longer distances /Ericson, 1980/.

The Baltic sea shore can be divided into four different types: rocky shores, shores with fractions of pebbles/moraine, sandy shores and shores with fine sediments. In the SFR area shores with various fractions of pebbles together with moraine are the most common; rocky shores and shores with fine sediments do occur.

The moraine shore with various fractions of pebbles have a sparse vegetation, even though the amount of nutrition may be high, which favour species like Lyme grass (*Elymus arenarius*), Marram (*Ammophila arenaria*), Scentless mayweed (*Matricaria perforata*), Oraches (*Atriplex spp*), Silverweed (*Potentilla anserina*) and Woad (*Isatis tinctoria*). On the rocky shores the lichen vegetation and the tree boarder grow close to the water line. Further up on the rocks, where there is available soil, the lichen zoning change into a community dominated by vascular plants. All species on the rocky shore are salt- and draught sufficient, e.g. Stonecrops, Plantains, Mayweed .

A general pattern for vegetation zonation in a sea shore site on the Baltic sea coast is hard to predict, because of local factors in the environment as the soil type (rock, boulder, pebbles, sand and fine sediment), the surrounding plant community systems and type of land use. When the fissure valley landscape occur in the coastal area, pine forest and exposed bedrock is found all the way down to the water level. In areas with pebbles or fine sediment the sea shore often is used for grazing, i.e. sea shore meadow, and the succession zonation is more fine scaled. A generalised zonation in a moraine shore is made for the SFR-area according to the land uplift rate. The Figure 3-5 is made as an example of one type of moraine/pebble shore in the SFR area, where different plant communities is presented.

Below, a general description of the zonation of the plant community on fine sediment in the Swedish archipelago, is given together with a presentation of the most common

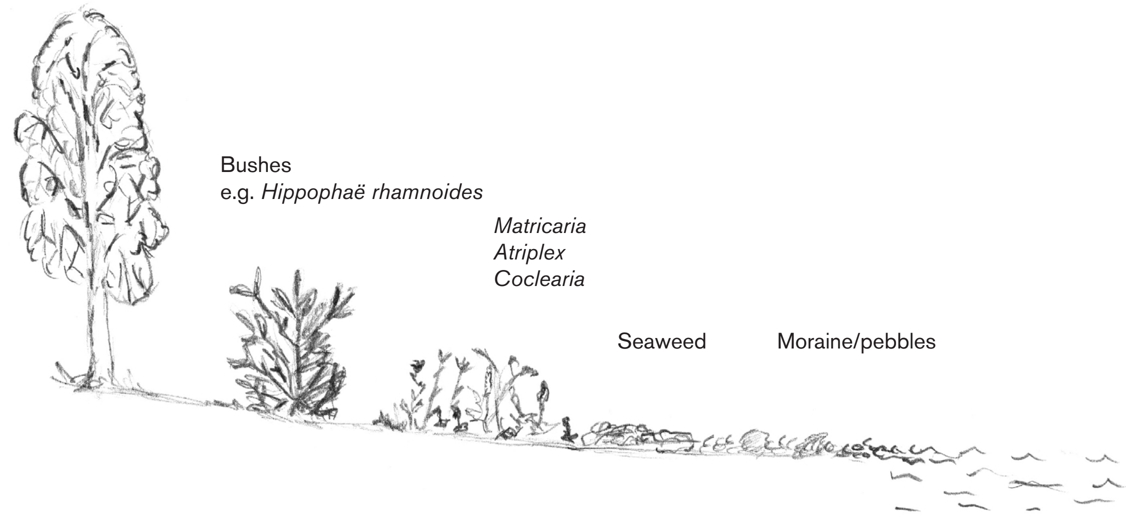


***Figure 3-5.*** *A generalised figure of an exposed moraine/pebble shore in the SFR region. The lower part of the sea shore is often poor with vegetation. Above the seaweed zone, salt and water tolerant species can establish. Further up shore bushes like Hawthorn" (Hippophaë rhamnoides) are common in front of a border of trees. Time scale according to land uplift rate.*

species. The size of the zones are not estimated since they are depending on how steep the slope is on the sea shore.

Zone 1) Because of the frequent inundations close to the shore line, this zone inhabit species with high water tolerance. Many species in this zone have the ability to store air bubbles for $CO_2$ supply. If the sea-meadow is grazed the zones are more sharp close to the reed-zone /Tyler, 1969/.

*Species:* Reed (*Phragmites australis*), Rush (*Schoenoplectus lacustris*), Horned pondweed (*Zannichella palustris*), Beaked tasselweed (*Ruppia maritima*).

Zone 2) Since the water level in the archipelago may have an amplitude of 1.5 metre, the species existing further up, in zone 2, must be able to tolerate flooding during some time during the year. Increased sedimentation makes it possible for species depending on deeper soil cover to establish.

*Species:* Tufted hairgrass (*Deschampsia cespitosa*), Slender spike-rush (*Elocharis uniglumis*), Sedges (*Carex spp*).

Zone 3) Further in land the ground is swampy which is favourable for several species. The species in this zone must also be able to tolerate frequent salt sprays.

*Species:* Saltmarsh rush (*Juncus gerardi*), Sea plantain (*Plantago maritima*), Sea milkwort (*Glaux maritima*).

Zone 4) The ground in the fourth zone is drier. Because of the evapotranspiration the ground dries up but the salt remains and creates a hard salt crust on the ground surface, for some species very difficult to penetrate. Therefore this zone is sparse with plants.

*Species:* Lesser Sea-spurrey (*Spergula salina*), Saltmarsh grass (*Puccinellia distans*), One-flowered glasswort (*Salicornia europea*).

Zone 5) On this level the plant community is similar to a sea-shore meadow.

## 3.4 Vegetation map of the present situation in the SFR

In the preparation of the vegetation map aerial photos of infrared types CIR (colour infrared) aerial photos (scale 1:30.000) photographed 1992 were used. The interpretations were made in a Wild Aviopret APT2, a Zooms stereo instrument. The results where thereafter transferred to ortogonal projection. The topographical map (13ISO Österlövsta) and two cadastral maps (ekonomiska kartbladen 13I0g Höggrunden and 13I0h Marträd) was used as support for the vegetation map. The smallest pixel used is 50 x 50 m.

There are no general systems for classifying vegetation but each system must be adapted to the objective of the investigation. The vegetation on these islands were interpreted into four main classes each again subdivided as follows:

1. Coniferous forests with a) more than 70 % and b) less than 70 % tree cover.
2. Mixed forests with a) more than 70 % and b) less than 70 % tree cover.
3. Deciduous forests with a) more than 70 % and b) less than 70 % closed canopy.
4. Open grassland a) dry to moist and b) moist to wet.

Apart from these rocky outcrops, gravel and excavated masses are indicated as well as bitumen coated roads and parking areas.

The present vegetation (Figure 3-6) follows the pattern described as general in several studies during the preceeding century /e.g. Du Rietz, 1948; Palmgren, 1915; Selander, 1954; Staav, 1972; Tapper, 1978/ i.e. shows a clear spatial vegetation pattern including three zones from the west (inner) to the east (outer) archipelago: an inner dominated by pine forest, an intermediate dominated by deciduous forests and an outer where exposed bedrock carrying few trees is most common /Du Rietz, 1948; Tapper, 1978/. Naturally the presence of larger islands, functioning as mainlands, may interrupt the pattern just as Gräsö eastwards from the model area does.

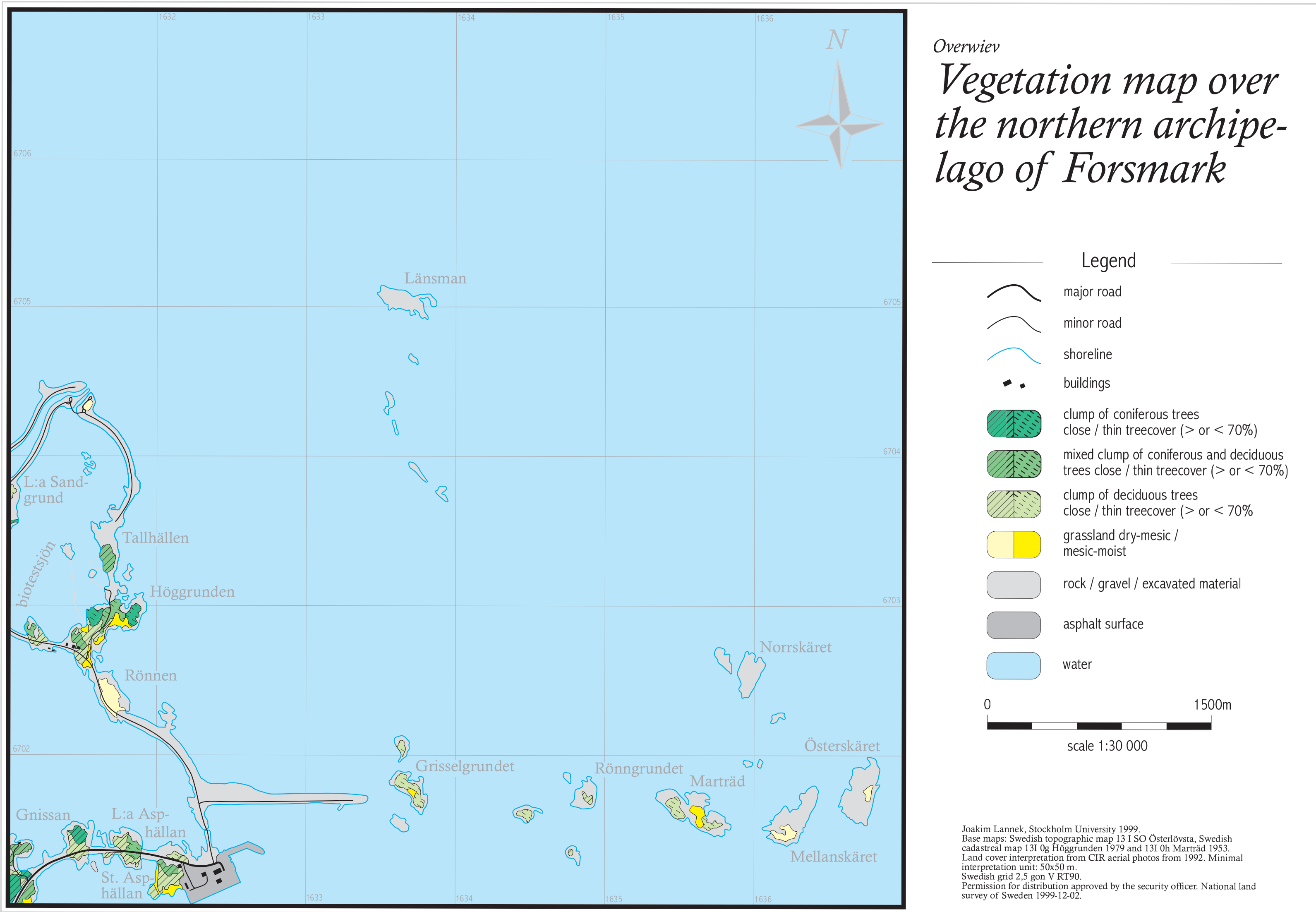


**Figure 3-6.** *Vegetation map of the SFR region in present time.*

## 3.5 Future vegetation of the model area

### 3.5.1 Assumptions

The model area consists geologically mainly of outwashed till rich in calcareous deposits with big boulders (a diameter between 1 and 2 m is common). The sedimentation in the future terrestrial areas will generally be small /Brydsten, 1999b/ with the exception from a few persistent lakes. Thus, only in a few places the sediment will be thick enough to cover the boulders. Therefore, we have made the assumption that only insignificant areas have the potential to be used for agricultural purposes at least with the techniques of today. However, we cannot foresee how techniques to exploit nature will be developed in the future. A good guess from the development up until today is that forestry will dominate the exploitation. We have therefore anticipated forestry as the dominating means of exploitation. Open land in general is confined to shores, mires and rocky outcrops of bedrock and will therefore be of little spatial significance. Open grassland (dry, moist and wet grasslands) are excluded since the significance of these categories becomes unimportant when management is excluded. The only type of open grasslands that will occur is shore meadows, which in absence of management, only will consist of a narrow fringe close to shores.

We have made the prediction that almost all terrestrial areas with a groundwater level below the soil surface eventually will end up in different types of forests just as it does today. The forest types will vary depending on the substrate and on the water content of the soil and its mobility. In areas with ground water level above the soil surface, lakes and mires will develop /Brunberg and Blomquist, 1999/ most of these will, however, sooner or later become forests.

The classes of vegetation predicted are kept on a generalised level. There are several reasons for this: first, that we want to emphasize the subjectiveness of the prediction, second that we are keen to make clear that the material is not to be regarded as a scientific prediction but rather as a good guess based on science.

Based on the vegetation map of the present situation and further on the dominating soil types of the area, the topography and closeness to the sea, transitions from aquatic to terrestrial vegetation were made. In addition, the altitude above sea level was used to predict the dominating types of vegetation. The smallest pixels used are 100 x 100 m – which is an increase compared to the map of present vegetation. This is made in order to make the reader aware of the change from observation to prediction.

It is obvious that any prediction of a future situation in the vegetation is subjective and relies on a number of assumptions. Basic assumptions that we have made are

a) that the climate is not changing but the change is driven mainly by the shore displacement,

b) that the shore displacement continues at the same speed for the whole future period as described by Brydsten /1999a/,

c) that the species pool remains relatively constant i.e. the species which are the dominating elements in the vegetation remains the same,

d) that the species do not change their ecological habits and the niches remains constant,

e) that human agriculture is absent in the area and the vegetation is left for free development or managed for forestry i.e. the cultural landscape is not taken into account.

All these assumptions are simplistic and force the predictions of future vegetation into a more deterministic direction than what the historic knowledge has taught us to be true. Thus, we have included a considerable part describing the historic development of the archipelago in order to stress the difference between predictions and historic facts.

### 3.5.2 The vegetation year 3000

Almost all of the Biotestsjön and the bay just south of it have become terrestrial and are covered with about equal parts of deciduous forests and mixed forests (cf Figure 3-7). Close to the remaining lakes reeds and woods of Alder (*Alnus glutinosa*) make up a fringe. The coast line is pushed outwards outside Grisselgrundet where the areas of highest elevation are covered with coniferous forest whereas lower areas carry deciduous forests in wet areas, mainly Alder (*Alnus glutinosa*). In the area about equal parts of deciduous and mixed forests will presumably develop. The skerries Länsman and the islands just south, as well as Norrskäret, Österskäret, Mellanskäret and Marträd, have grown into one island where deciduous forests dominate. Rönngrundet has grown considerably into terrestrial areas dominated by deciduous forests although mixed forests occur. New islands have emerged further out in the Öregrundsgrepen. They contain either open land on rocky outcrops of bedrock or deciduous forests, close to the shore line where sediments or organic material is thick enough. Many of the coves and flades will be colonised by reeds.

In conclusion, the flora will presumably be very close to the one seen in corresponding areas of today.

### 3.5.3 The vegetation year 4000

A major part of the SFR area is at this time terrestrial (cf. Figure 3-8). There remains a bay with only a narrow mouth to the sea (which is not seen in the map). This bay will presumably be encroached by reeds and rushes (not indicated) which makes the area appear as open wet grassland. The lower parts of the coastal area will be covered by deciduous forests. The forests is now mainly consisting of Alder (*Alnus glutinosa*) in wet areas whereas Ash (*Fraxinus excelsior*) will dominate in less wet sites. Slightly drier, in moist ground, aspen is expected to colonise. The deciduous forests will successively be invaded by coniferous trees – in dry areas (and in mires) by pine whereas spruce instead will be most abundant in moist areas.

In areas of higher altitude mixed forests will be replaced by coniferous forests with pine dominating in dry, and spruce in moist, areas.

### 3.5.4 The vegetation year 5000

A large and a small lake is now left in the SFR area (cf. Figure 3-9). The coniferous forests dominate although in lower areas such as the former bay the mixed forest element is significant. The pure decidious forest type is reduced to moister areas in depressions and along the shores of the lakes and to areas where the terrestrial habitat are of more recent date. The composition of species and their habitat requirements will follow the patterns already described in former sections.

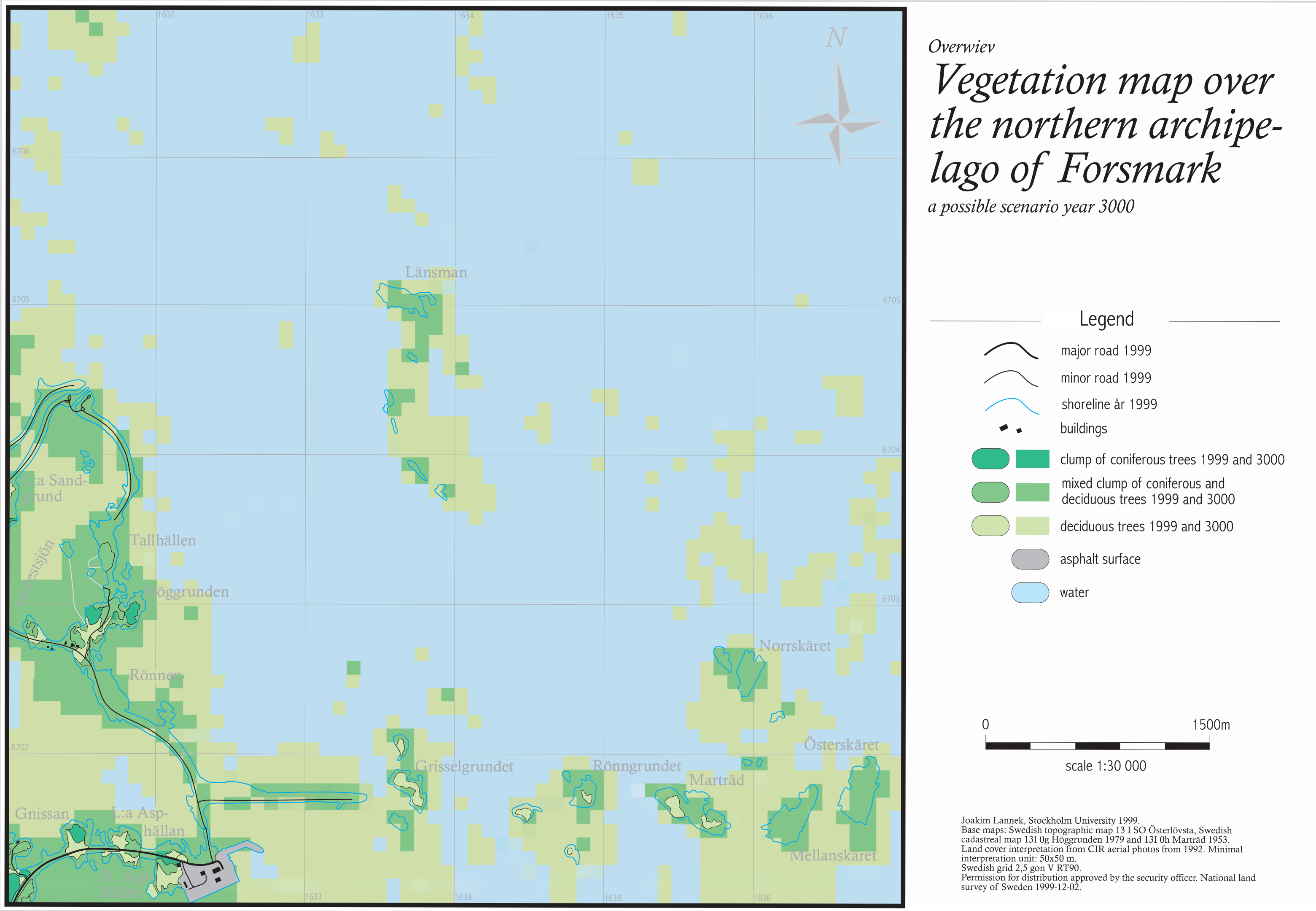


***Figure 3-7.*** *Vegetation map of year 3000.*

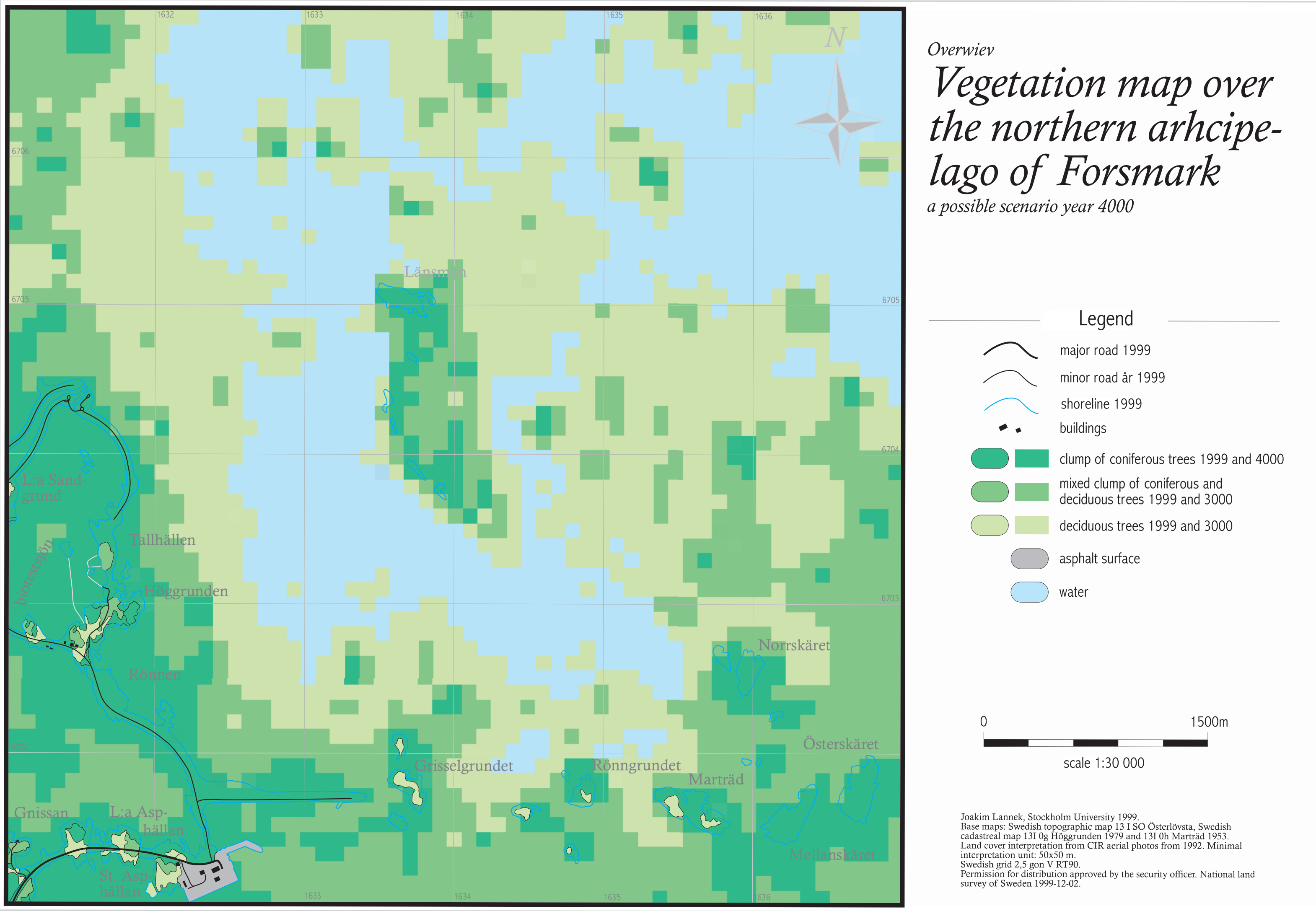


***Figure 3-8.*** *Generalised map of the predicted vegetation year 4000.*

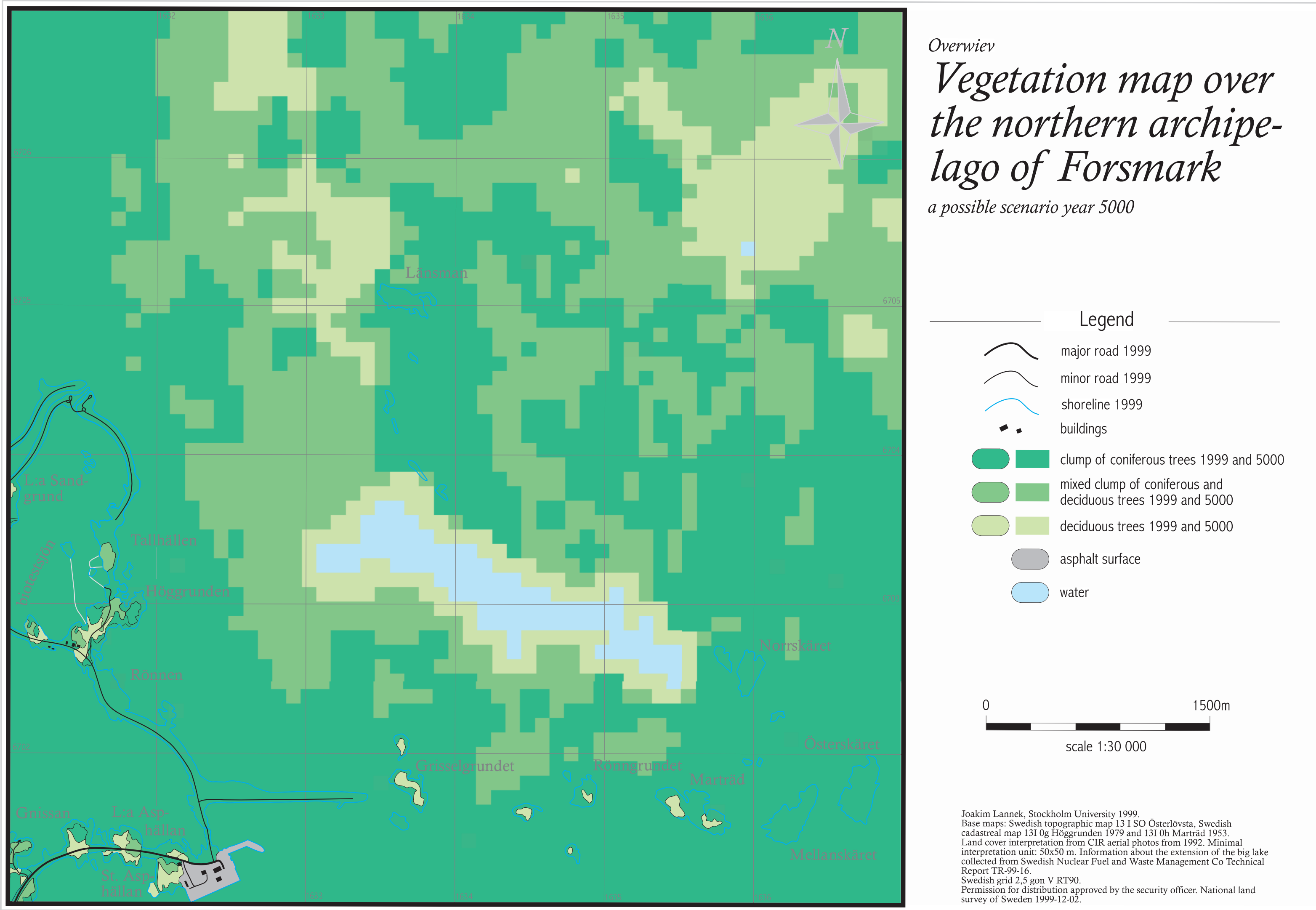


**Figure 3-9.** *Generalised map of the predicted vegetation year 5000.*

### 3.5.5 Conclusions

The development of the vegetation on the rising shores of the area is the result of colonisation and extinction of species. Colonisation has proceeded by the slow migration into the area of new species. The present knowledge of the colonisation process is by far not complete and this makes predictions hard to make on a more detailed level. The colonisation of Spruce (*Picea abies*), for example, has lately been reassessed and backdated by several thousand years. This illustrates how shallow the knowledge is about the colonisation process that we have. The situation is the same for our knowledge concerning extinction of species. Further, the dynamics in the vegetation is driven by different kinds of disturbances such as forest fire, erosion, floodings, storm-felling etc. which in turn are affected by the climatic development.

However, with not too far going changes in climate it is likely that on a general level coniferous forests, mixed forests and deciduous forests will dominate the emerging islands as we have outlined in the vegetation maps above. The future human management of the area is impossible to predict. Many factors such as the demographic development, technical innovations and the food supply situation will affect the utilisation of the area. We have left out speculations concerning this.

Which type of vegetation that develops is of great importance for the transport of the components of organic material e.g. carbon. In general dry areas, where access to oxygen is good, the decomposition of organic material is fast. This means that carbon is readily released into the atmosphere as carbon dioxide. In wet areas, mires and lake-sediments, the decomposition is slow due to oxygen deficit and organic production exceeds decomposition i.e. carbon is accumulated. The relative element of wet and dry areas is therefore important for the carbon release-accumulation balance.

In the model area, wetlands will generally be replaced by dryer areas in the future. This will increase the release of carbon. However, in depressions, lakes and mires will dominate which in turn will reduce the mobility of carbon. The net effect of this has to be analysed by an estimation of the relative area of different ecosystems together with data concerning carbon fixation and decomposition for each type of ecosystem.

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# 5 Glossary of latin names

| Latin name | English name | Swedish name |
|---|---|---|
| *Alces alces* | Elk | Älg |
| *Allium schoenoprasum* | Chives | Gräslök |
| *Allium ursinum* | Ranson | Ramslök |
| *Alnus glutinosa* | Alder | Klibbal |
| *Alnus incana* | Grey alder | Gråal |
| *Ammophila arenaria* | Marram | Sandrör |
| *Artemisia sp.* | Mugworts | Gråbo, malört |
| *Athyrium filix-femina* | Lady fern | Majbräken |
| *Atriplex sp.* | Oraches | Målla |
| *Betula pendula* | Birch | Vårtbjörk |
| *Campanula sp.* | Bellflowers | Blåklocka |
| *Capreolus capreolus* | Roe deer | Rådjur |
| *Carex sp.* | Sedges | Starr |
| *Castor fiber* | Beaver | Bäver |
| *Centaurea sp.* | Knapweeds | Klint |
| *Chara sp.* | Charas | Kransalg |
| *Corylus avellana* | Hazel | Hassel |
| *Deschampsia caespitosa* | Tufted hairgrass | Tuvtåtel |
| *Dryopteris filix-mas* | Male fern | Träjon |
| *Eleocharis uniglumis* | Slender spiked rush | Agnsäv |
| *Fraxinus excelsior* | Ash | Ask |
| *Glaux maritima* | Sea milkwort | Strandkrypa |
| *Hippophaë rhamnoides* | Hawthorn | Havtorn |
| *Hordelymus europaeus* | Wood barley | Skogskorn |
| *Isatis tinctoria* | Woad | Vejde |
| *Juncus gerardi* | Saltmarsh rush | Salttåg |
| *Lepus sp.* | Hare | Hare |
| *Martes martes* | Marten | Mård |
| *Matricaria perforatum* | Scentless mayweed | Baldersbrå |
| *Meles meles* | Badger | Grävling |
| *Mustela vison* | Mink | Mink |
| *Phragmites australis* | Common reed | Vass |
| *Picea abies* | Spruce | Gran |
| *Pinus sylvestris* | Pine | Tall |
| *Plantago lanceolata* | Ribwort plantain | Svartkämpar |
| *Plantago maritima* | Sea plantain | Gulkämpar |
| *Plantago media* | Hoary plantain | Rödkämpar |
| *Plantago sp.* | Plantains | Kämpar |
| *Polypodium vulgare* | Polypody | Stensöta |
| *Populus sp.* | Aspen | Asp, poppel |
| *Potentilla anserina* | Silverweed | Gåsört |
| *Puccinellia distans* | Reflexed saltmarsh grass | Saltgräs |
| *Quercus robur* | Oak | Ek |
| *Ribes alpinum* | Mountain currant | Måbär |
| *Rumex sp.* | Sorrels | Skräppa, syra |
| *Ruppia maritima* | Beaked teaselweed | Hårnating |

| Latin name | English name | Swedish name |
|---|---|---|
| *Salicornia europaea* | Common glasswort | Glasört |
| *Salix sp.* | Willows | Sälg, vide |
| *Schoenoplectus lacustris* | Rush | Sjösäv |
| *Sedum acre* | Biting stonecrop | Grul fetknopp |
| *Sedum sp.* | Stonecrops | Fetknopp, kärleksört |
| *Silene uniflora* | Sea campion | Strandglim |
| *Sorbus aucuparia* | Rowan | Rönn |
| *Sparganium sp.* | Bur reeds | Igelknopp |
| *Spergula salina* | Lesser sea spurrey | Saltnarv |
| *Sphagnum sp.* | Peat mosses | Vitmossa |
| *Taxus baccata* | Yew | Idegran |
| *Thalictrum sp.* | Meadow rues | Ruta |
| *Tilia sp.* | Lime tree | Lind |
| *Trifolium repens* | White clover | Vitklöver |
| *Typha angustifolia* | Lesser Bulrush | Smalkaveldun |
| *Ulmus glabra* | Elm | Alm |
| *Viburnum opulus* | Guelder rose | Olvon |
| *Vulpes vulpes* | Fox | Räv |
| *Xanthoria parietina* | | Vägglav |
| *Xanthoria ramalina* | | Brosklav |
| *Zannichellia palustris* | Horned pondweed | Särv |