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Oskarshamn/Forsmark site investigation

Estimation of biomass and net primary production in field and ground layer, and biomass in litter layer of different vegetation types in Forsmark and Oskarshamn

Anders Löfgren, EcoAnalytica

April 2005

Svensk Kärnbränslehantering AB
Swedish Nuclear Fuel
and Waste Management Co
Box 5864
SE-102 40 Stockholm Sweden
Tel 08-459 84 00
+46 8 459 84 00
Fax 08-661 57 19
+46 8 661 57 19

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Abstract

In the process of siting a deep repository for spent nuclear fuel SKB performs extensive site investigations in order to present a proposal of how a deep repository for spent nuclear fuel can be built and operated. To describe the surface system, a comprehensive descriptive ecosystem model will be constructed. The aim of this report is to provide reasonable estimates of a number of properties describing the biomass in the field, ground and litter layer, and the net primary production (NPP) in the field and ground layer in a number of vegetation types at the two potential sites for a deep repository, Forsmark and Oskarshamn. All data have been collected at the two sites, except data covering root and lichen NPP that have been estimated using generic data of the relationship between biomass and NPP. The results suggest that the estimates are reasonable, but reveal a large variation within the vegetation types. Few or no studies have presented estimates that cover most of the different components that together constitute the field and ground layers above and below ground, which make comparisons with other studies difficult. NPP estimates for a number of bryophyte species are also presented.

Sammanfattning

SKB arbetar med att undersöka två platser som är potentiellt lämpade för slutförvar av använt kärnbränsle. I detta arbete presenteras data som kommer att användas i beskrivande ekosystemmodeller för respektive plats. Data beskriver biomassa och primärproduktion för fält- och bottenskikt, samt biomassa för förnaskiktet i sex vegetationstyper i Forsmark och sju vegetationstyper i Oskarshamn. Den största delen av data har insamlats på platserna och beskriver förhållandena för år 2004. Undantagen är primärproduktion för rötter samt lavar, där generiska data har använts. Resultaten tyder på en stor variation inom och mellan vegetationstyper. Resultaten jämförs även med andra undersökningar och får under de givna förutsättningarna anses utgöra en god grund för fortsatta beskrivningar.

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1 Introduction

In the process of siting a deep repository for spent nuclear fuel, SKB has the responsibility to investigate and present detailed proposals of how a deep repository can be built and operated. The extensive site investigations that have to precede the proposals comprise several different disciplines such as geology, hydrology, chemistry and ecology /SKB, 2001/, which in the end all have to be integrated and evaluated in order to construct a proposal for a deep repository.

The site investigations covering the surface ecosystem started in 2002 with the aim of building a comprehensive descriptive ecosystem model for the terrestrial, limnic and marine environments at each potential site for a deep repository /Löfgren and Lindborg, 2003/. These descriptive ecosystem models will provide the safety analysis with the necessary data to estimate and predict transport and accumulation of radionuclides using information describing budgets of carbon, nitrogen and phosphorous /Löfgren and Lindborg, 2005/.

The aim of this report is to provide reasonable estimates of a number of properties describing the biomass in the field, ground and litter layer, and the net primary production (NPP) in the field and ground layer in a number of vegetation types at the two potential sites for a deep repository, Forsmark and Oskarshamn.

This document reports the results gained by the activity named as "Uppskattning av växtbiomassa och primärproduktion i fält-, mark- och förnaskikt", which is one of the activities performed within the site investigation at Forsmark and Oskarshamn. The work was carried out during 2004 in accordance with the activity plans listed in Table 1-1. The activity plans are SKB's internal controlling documents. The original results are stored in the primary data base (SICADA) and are traceable by the activity plan number.

Table 1-1. Controlling documents for performance of the activity.

Activity plan	Number	Version
Uppskattning av växtbiomassa och primärproduktion i fält-, mark- och förnaskikt	AP PO 400-04-049	1.0
–"–	AP PF 400-04-51	1.0

2 Objectives and theoretical background

2.1 Objectives

The purpose of this study is to provide reasonable estimates of a number of properties describing the biomass in the field, ground and litter layer, and the net primary production (NPP) in the field and ground layer in a number of vegetation types at the two potential sites for a deep repository, Forsmark and Oskarshamn. Most of these properties are estimated at the site, but some have been estimated using literature values in lack of field estimates from the site (Table 2-1). The properties describing the different layers are,

1. Biomass separated into green and woody parts above ground (AG).
2. Biomass below ground (BG).
3. Net primary production above ground (NPP AG).
4. Net primary production below ground (NPP BG).

Table 2-1. A summary of the different properties that are estimated in this report.

Layer	Property	Local/Generic	Reference
Field layer	Dwarf schrub green biomass	L	
	D.S. woody biomass	L	
	D.S. green NPP	L	
	D.S. woody NPP	L	
	Herb biomass	L	
	Herb NPP	L	
	Root biomass	L	
	Root NPP	G	/Saugier et al. 2001/
Ground layer	Lichen biomass	L	
	Lichen NPP	G	/Malm, 2002/
	Moss biomass	L	
	Moss NPP	L	
Litter layer	Biomass	L	

2.2 Theoretical background

The estimation of biomass in the field and ground layer is based on one sampling occasion that should reflect the biomass for the specific vegetation type. This means that the sampling occasion has to be carefully located in time, depending on the annual vegetation dynamics. Among functional groups with a large part of their NPP manifested in green plant tissue, which has an annual turnover, the biomass increases until a point where older plant parts senesce or are shed, and become replaced by newer parts. The replaced biomass starts to decompose during the same year. The sampling occasion is therefore a trade-off between the point where as little necromass as possible has decomposed and when the NPP has decreased to a low level. In this study the sampling occasion has taken place in the late part of the vegetation period when the maximum biomass is expected to be found. The vegetation period at the two sites differs and therefore the sampling occasion reflects the vegetation period at the two sites, e.g. the time for harvest is earlier for Forsmark than for Oskarshamn and the length increment measures for bryophytes cover a slightly shorter time period for Forsmark than for Oskarshamn (Table 2-1).

NPP is the difference between gross primary production (GPP) and plant respiration and is defined 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/. NPP in the field layer may similarly be estimated using the premises that the occasion for the sampling reflects the accumulated biomass for a vegetation period. Such an estimate should preferably also include the shed parts during the vegetation period. This measure may be more complicated for bryophytes and lichens because they are more tolerant to temperature and are always prepared to use a "window of opportunity" when the microclimate is suitable for primary production /e.g. Busby et al. 1978/ and are thus not only confined to the normal vegetation period /Tamm, 1953/.

3 Methods

3.1 The sites and the vegetation types

The fieldwork has been conducted at the two sites Forsmark and Oskarshamn where seven different vegetation types have been investigated (Figure 3-1). A number of site characteristics of interest to the investigation are listed in Table 3-1. The vegetation types investigated were chosen in accordance with an earlier study focusing on the soil performed by /Lundin et al. 2004, 2005/. They identified a number of vegetation types as representative for the soil distribution at the two sites. Each soil class was investigated in regard of the floristic composition and a number of chemical parameters such as pH, N and C content.

A subset of these vegetation types was selected to represent the most dominant field and ground layer types, and to cover vegetation types that may have a high potential for accumulating organic material, e.g. mires, and also to represent vegetation that have a high potential to be used by humans, e.g. grasslands. The vegetation types that were chosen are very much of the same type at both sites (Table 3-2 and 3-3) making comparisons possible. In this study the spots used for sampling were the same as previously used by /Lundin et al. 2004, 2005/, with two exceptions, making further comparisons possible. The exceptions were for the vegetation types with thin soil layer (≥ 0.5 m). These plots were relocated to areas containing exposed bedrock (intermingled with a thin soil layer) as close as possible to the original plots. One sampling locality representing the vegetation type shoreline in Forsmark was unfortunately lost due to a high water level at the time for harvest.

3.1.1 The Forsmark site

Seven different localities were chosen to represent seven vegetation types (Figure 3-2, Table 3-2). They were selected from the eight localities identified by /Lundin et al. 2004/ as representing the most important soil classes at the site. One of the vegetation types, the herb dominated moist soils with a rather sparse tree layer, had periods of grazing by cows, which affects the estimations of biomass and NPP in that vegetation type.

3.1.2 The Oskarshamn site

Seven different localities were chosen to represent seven vegetation types (Figure 3-3, Table 3-3). They were selected from the ten localities identified by /Lundin et al. 2005/ as the most important soil classes at the site. One of the vegetation types, the grassland, had periods of grazing sheep, which may affect the estimations of biomass and NPP in that vegetation type.

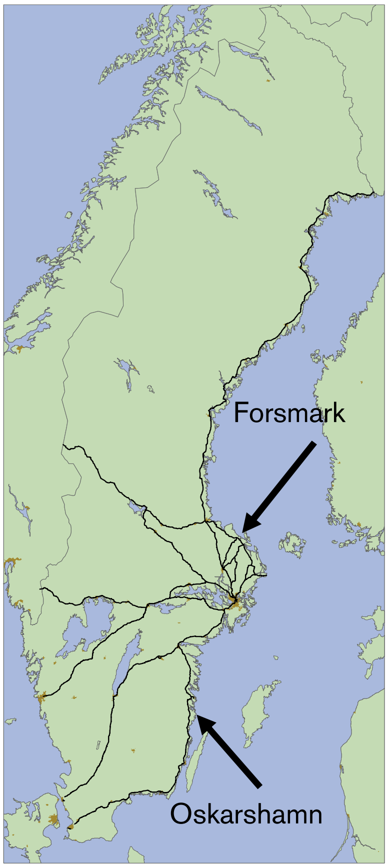

***Figure 3-1.** The location of the two sites Forsmark and Oskarshamn in Sweden.*

Table 3-1. Some climate characteristics for the two sites and fieldwork related information.

	Forsmark	**Oskarshamn**
Latitude, longitude	60° N, 18° W	57° N, 16° W
Mean annual temp. 2004[1]	+6°C	+7°C
Precipitation (mm)	900	600
Vegetation period	May–September	April–Oktober
Vegetation period (No of days)	180	195
Start of bryophyte measuring	2004-04-13 to 14	2004-04-01 to 02
Harvest	2004-09-14 to 16	2004-09-20 to 22
Days between start and harvest	155	173
Number of habitats investigated	6[2]	7

1) /SMHI, 2004/.

2) The shoreline locality at the Forsmark site was lost due to high water level at the time for harvest.

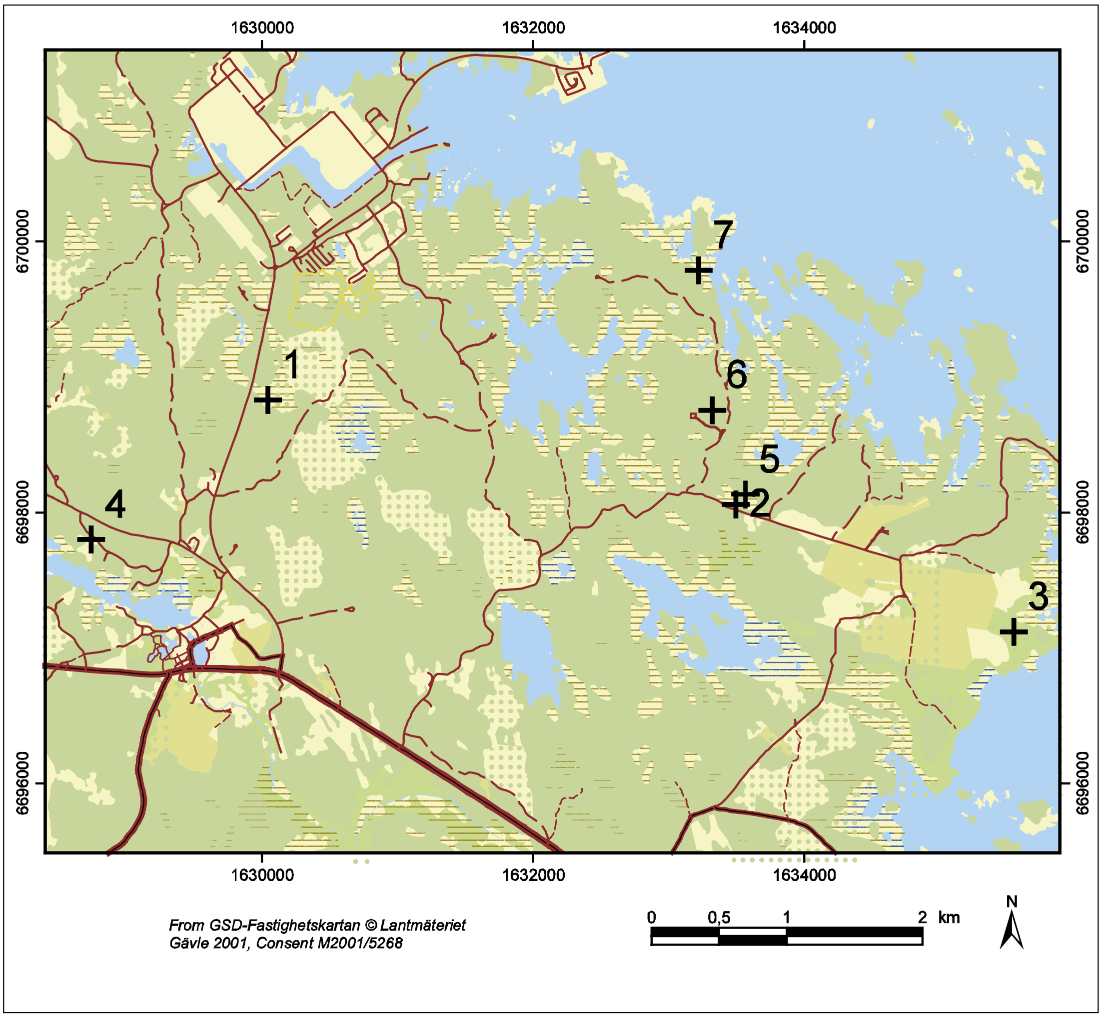

Figure 3-2. *The localities that were selected to represent the seven different vegetation types in Forsmark, see /Lundin et al. 2004/ for a more detailed description.*

Table 3-2. Nomenclature describing the localities that were sampled in Forsmark. The localities are the same as in /Lundin et al. 2004a/.

Nr	Vegetation type	Lundin's Id	X	Y	SKB id-codes
1	Mires	T2	6698828	1630045	AFM001079
2	Forested wetlands	SS1	6698060	1633495	AFM001076
3	Herb dominated moist soils on fine texture parent material	FL2	6697118	1635547	AFM001071
4	Grasslands	A2	6697798	1628742	AFM001081
5	Wood land, coniferous forest	FG1	6698130	1633565	AFM001068
6*	Thin soils, lichen rich vegetation	B3	6698753	1633324	AFM001067
7	Shore line (bedrock excluded)	S2	6699785	1633223	AFM001075

* This site was moved 100 m from the sample locality used by /Lundin et al. 2004/.

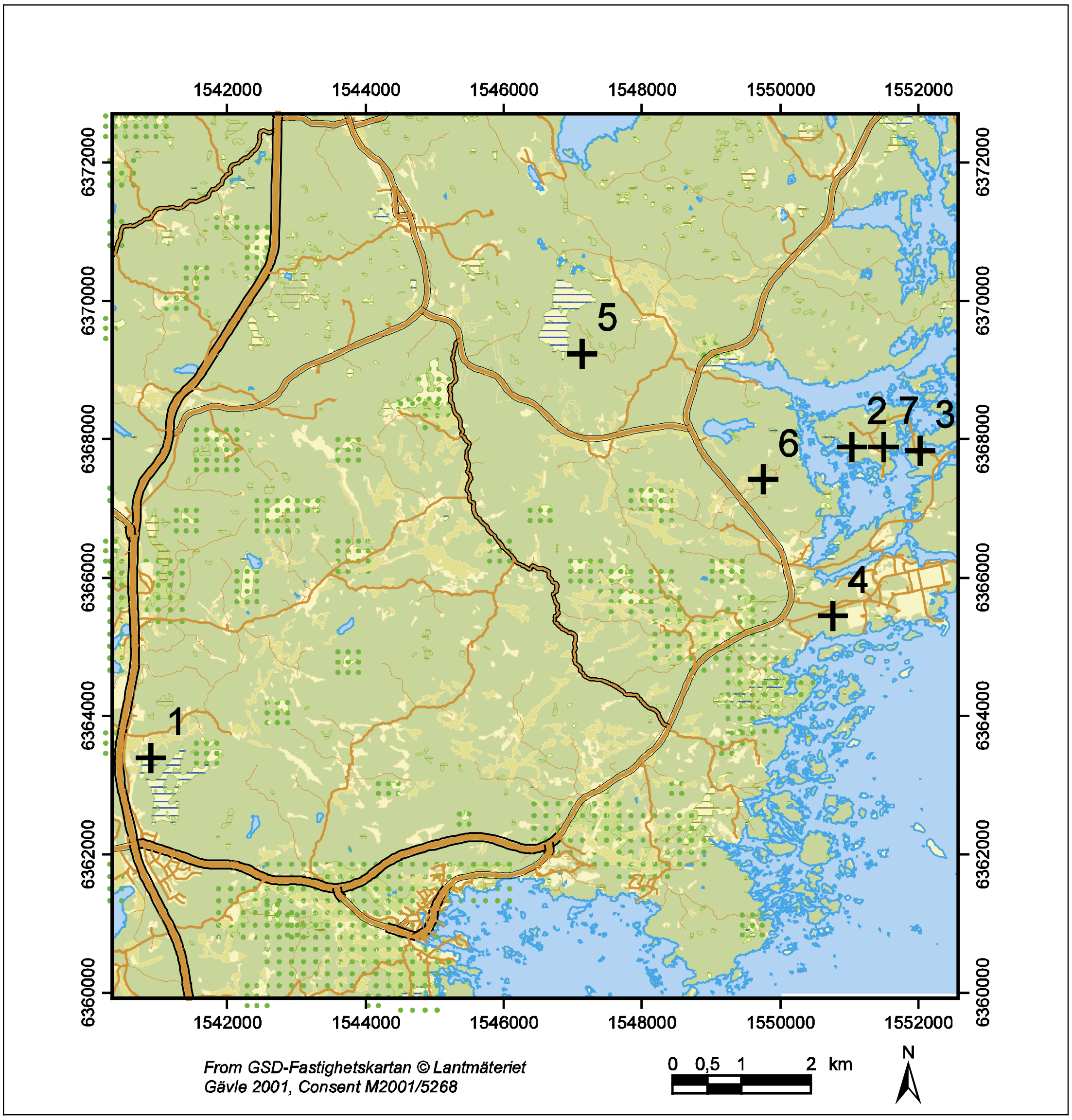

Figure 3-3. *The localities that were selected to represent the seven different vegetation types in Oskarshamn, see /Lundin et al. 2005/ for a more detailed description.*

Table 3-3. Nomenclature describing the localities that were sampled in Oskarshamn. The localities are the same as in /Lundin et al. 2005/.

Nr	Vegetation type	Lundin's Id	X	Y	SKB id-codes
1	Mires	Våt 2	6363396	1540912	ASM001443
2	Forested wetlands	Sump 1	6367881	1551023	ASM001434
3	Herb dominated moist soils on fine texture parent material	Löv 1	6367828	1552003	ASM001426
4	Grasslands	Äng 1	6365445	1550750	ASM001430
5	Woodland, coniferous forest	Gran 1	6369225	1547128	ASM001440
6*	Thin soils, lichen rich vegetation	Häll 2	6367410	1549746	ASM000210
7	Shore line (bedrock excluded)	Strand 1	6367884	1551478	ASM001436

* This site was moved 40 m from the sample locality used by /Lundin et al. 2005/.

3.2 Field work

Sampling plots were located at the same localities as in /Lundin et al. 2004, 2005/, using a systematic design (Figure 3-4). A large stick was put into the ground in the north-east corner of the central square while smaller sticks were put into the north-east corner of the four outer plots. If a plot was located on a rock or a tree, the square was relocated turning it around, having the north-east corner fixed. A smaller 0.25×0.25 m plot was located in the upper north–west corner of the 0.5×0.5 m plot.

The most abundant ground layer moss species were identified. A number of sets of five shoots per set were established where individual shoots were marked with a thread tied around the shoot 1.5 to 3 cm below the top in close proximity to the plots. The length between the top and the thread was measured individually for each shoot.

In wetland habitats containing Sphagnum species the so called "cranked wire method" /Clymo, 1970/ was used to measure the length increment. A cranked steel wire is put into the substrate and the crank is located in height with the shoots. The increase in height of the shoots is then measured in relation to the "crank" at the time for the return visit. Cranked wires were put in hummocks ("tuvor"), hollows ("höljor") and an intermediate position to represent both wetter and drier conditions. Localisation of cranked wires was always accompanied by a sample of the Sphagnum species for identification.

The plots were revisited in the autumn when the marked moss shoots were collected and a density sample was collected to each set of five shoots. The density sample was taken from a 1×1 dm area with moss shoots representative of the set. Coverage of the field layer was estimated using multiples of 1 dm^2 squares within the 0.25×0.25 m area located in the upper north–west corner of the 0.5×0.5 m plot, and then harvested. The different fractions; dwarf shrubs and herbs, were separated in the field.

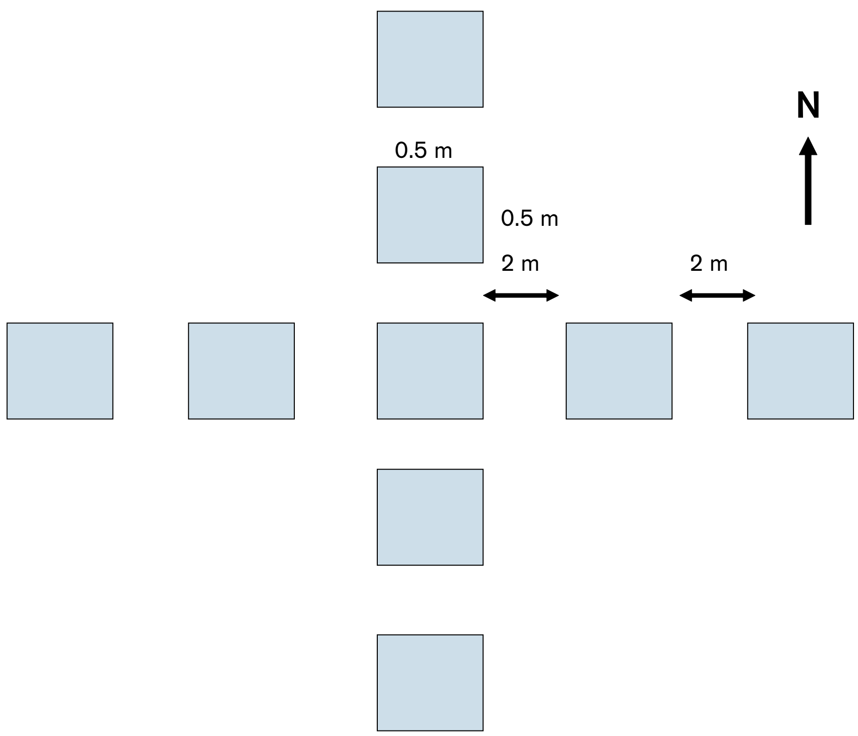

Figure 3-4. *The design of the sampling plots in each vegetation type.*

The ground layer (bryophytes and lichens) cover was then estimated, the three most dominant species identified, and all bryophytes and lichens were collected within the 0.25×0.25 m plot. The coverage of the litter layer was estimated, and then sampled in the plot and the dominating component identified. A root sample was collected by sampling a 0.25×0.25 m plot. The depth varied depending on the soil depth and boulder frequency.

3.3 Lab work and analysis

All lab work was conducted by the staff at the Jädrås field station, SLU (Swedish University of Agriculture Sciences), except for the part concerning the estimates of bryophyte NPP, which was performed by Vanja Alling and the author.

3.3.1 Biomass of field, ground and litter layer

Dwarf shrubs were separated into the following fractions: berries, green parts (previous years), green parts (this year), woody parts (previous years), woody parts (this year) and dead parts. Field layer (grasses and herbs), bryophytes, lichens and litter were separated if not already done. Dead material was assigned to the litter fraction.

The samples were dried in 80°C for 48 hours, cooled in an exicator for two hours and thereafter weighed.

The root samples were dried in 80°C for 48 hours and sieved, and dried again. These samples were let to cool in the drier and thereafter weighed. The root samples contained both larger roots and fine roots. The roots of *Phragmites australis* were difficult to separate from mud so these samples may be more or less affected by other than roots. The root fraction contains both live and dead roots.

3.3.2 NPP of vascular plants and dwarf shrubs

NPP of vascular plants was estimated using the assumption that all green tissue for herbs and grasses was produced during the present year. NPP of dwarf shrubs was estimated using the assumption that all green tissue produced this year, together with woody parts produced this year, equalled the NPP.

3.3.3 NPP of bryophytes

The collected moss shoots were measured and the difference between the first and second measurement was calculated (see Table 4-7 for sample sizes). In some cases the length had decreased or stayed nearly constant, probably as a result of disturbances or herbivory. These were not treated differently and were therefore included in the calculations of length increment. In a few cases the entire shoot had disappeared and was excluded.

A relationship was established between length and dry weight using five moss shoots from the density samples. The upper part (2 cm) was removed and dried in 60°C for 6–24 hours, depending on the size of the samples. On species with an accentuated top meristem (*Sphagnum sp, Polytrichum sp* and *Rhytidiadelphus triquestris*) the top was removed, thereby not including the enlarged top meristem in the calculation of weight per unit length. In pleurocarp species the side branches were left on the main stem, thereby including these in the estimate.

Each density sample yielded a mean of weight per unit length of stem, which was used to convert the length increment for the moss shoots within each spot to weight per shoot. The latter was turned into a measure of increase in dry weight per dm^2 using the density of the shoots. This calculation was used to calculate an estimate per m^2 using the coverage percent for the specific moss species within each plot.

Only the dominant two or three species were used when calculating the NPP. The production of other species was calculated using the production estimate for the sampled species best resembling that species, e.g. acrocarp/pleurocarp, size etc.

In some cases no effort was made to separate between species, e.g. in the mire where brown mosses (species belonging to genera such as *Calliergon, Campylium, Drepanocladus, Scorpidium* and *Warnstorfia*) dominate in Forsmark, and between Sphagnum species that dominate mires in Oskarshamn. However, all measured species were complemented with a sampled specimen, making further separation into species possible. The nomenclature describing the names of the bryophytes is following /Söderström and Hedenäs, 1998/.

3.3.4 NPP of lichens

Few studies on NPP of lichens in the ground layer are available, and these have been done in arctic and tundra regions to study effects of reindeer grazing. I have here used an estimate of NPP as an 11.5% yearly increase of biomass (of the total biomass) originating from the north of Sweden /Malm, 2002/.

3.3.5 Roots

Biomass

The estimation of root density is difficult due to problems with boulders and variation in the soil depth. Here the following simplifying assumption is used. Each root sample reflects the local possibility to penetrate and accumulate biomass in the soil. Each sample is taken as deep as possible (with the premises set by the equipment used). So the varying sample depth among the root samples reflects the actual root distribution within the vegetation type. This assumption tends to underestimate the actual root biomass. In boreal forests approximately 70% of the root biomass is found in the upper 20 cm /Jackson et al. 1996/.

In vegetation types with a tree layer, roots from that layer are represented in root biomass samples. Few studies have presented a detailed resolution of the relationship between roots of field and tree layer. Correction for tree roots was taken from /Majdi and Andersson, 2004/ who found that the field layer roots represented 38% of the total root biomass in the Flakaliden experimental area in northern Sweden. This correction was applied to the vegetation types that had a tree layer (forested wetland, herb dominated moist soils, coniferous forest and thin soil).

For three different vegetation types in Forsmark one root sample was missing. When calculating the total biomass and NPP for the squares a mean from the four other root samples was used.

NPP

This parameter was not measured but estimated using data from a summary of NPP in major biome types /Saugier et al. 2001/. A generic value from temperate grasslands was used for all habitats (NPP BG is twice that of NPP AG). One important reason for this is that estimates from equivalent vegetation types with a tree layer, as in this investigation, do not separate between roots belonging to the tree layer and the field layer. This is also the reason why the estimate of NPP BG is built upon what has been quantified as AG and not the actual root biomass.

3.4 Statistics

All statistical calculations such as mean, median and standard deviations were performed in Excel 2002. Graphs were made within Statistica 6.0.

The mean has been used to illustrate the central value of the different properties, even though the sample size of 5 may be regarded as fairly small. In some cases this fits badly with the distribution of the five samples, but is in most cases a fairly good approximation.

The different fractions have been presented separately to illustrate e.g. what the field layer is composed of. These fractions are not just added to get a total sum. The total biomass and NPP for each vegetation type have been calculated, adding all fractions within each sample plot and thereafter the mean and standard deviations have been calculated using the plots.

4 Results

4.1 The field layer

The biomass of the field layer was largest in the mire both in Forsmark and Oskarshamn closely followed by the shore with Phragmites australis in Oskarshamn (Table 4-1, 4-2). These vegetation types also demonstrated the largest NPP. The second most productive vegetation type was the grassland. The most productive field layers were found in vegetation types lacking tree layer. The lowest field layer NPP was found in the forested wetland in Forsmark and the coniferous forest in Oskarshamn. Biomass and NPP are expressed as dry weight (gdw) per square metre or per square metre and year respectively.

Table 4-1. Mean values for biomass and NPP for different fractions of the field layer in Forsmark. Green is the green fraction from all herbs, grasses and shrubs (including the winter green fraction from dwarf shrubs e.g. *Vaccinium vitis-idae*). All values are in gdwm^{-2} except NPP that is in gdwm^{-2} y^{-1}. Standard deviation is presented after the mean.

Parameters	Mire	Forested wetland	Herb dominated moist soil	Grassland	Coniferous forest	Thin soil
Green biomass	154±40	6±5	62±35	275±82	40±23	188±128
Biomass woody parts	28±33	0	5±4	0	1±2	55±42
Dead biomass	0	0	0	0	0	8±8
Biomass berries	0	0	0	0	0	2±2
Biomass roots	3,573±2,130	203±139*	101±23*	558±140	387±194*	265±79*
Dominating species	*Phragmites australis, Carex sp*	*Filipendula ulmaria, Rubus saxatilis*	*Elymus caninus, Geum rivale, Viola sp*	*Elymus repens, Dactylis glomerata*	*Viola riviniana, Melica nutans, Maianthemum bifolium*	*Vaccinium vites-idaea, Empetrum nigrum.*
NPP AG	162±40	6±5	64±33	275±82	40±24	120±107
Calculated BG NPP	324±79	12±10	128±67	550±164	81±48	239±214

* Correction for presence of tree roots.

Table 4-2. Mean values for biomass and NPP for different fractions of the field layer in Oskarshamn. Green is the green fraction from all herbs, grasses and shrubs (including the winter green fraction from dwarf shrubs e.g. *Vaccinium vitis-idae*). All values are in gdwm^{-2} except NPP that is in gdwm^{-2} y^{-1}. Standard deviation is presented after the mean.

Parameters	Mire	Forested wetland	Herb dominated moist soil	Grassland	Coniferous forest	Thin soil	Shore
Green biomass	170±81	29±28	88±26	156±65	8±7	41±22	103±105
Biomass woody parts	218±455	0	2±5	0	1±3	13±7	0
Dead biomass	13±29	0	0	0	0	1±1	0
Biomass berries	0	0	0	0	0	0	0
Biomass roots	2,284±1,035	656±697*	264±204*	765±335	536±342*	146±42*	2,525±1,321
Dominating species	*Carex rostrata, Potentilla palustris, Equisetum fluviatile*	*Calamagrostis canescens, Carex nigra*	*Deschampsia flexuosa, Melica nutans, Agrosits capillaris*	*Deschampsia ceaspitosa, Agrostis capillaries, Achillea millefolium*	*Carex sp (non-fertile), Vaccinium myrtillus,*	*Vaccinium vites-idaea, Deschampsia flexuosa*	*Phragmites australis, Agrostis stolonifera*
NPP AG	197±138	29±28	88±26	156±65	8±7	41±22	103±105
Calculated BG NPP	395±276	57±56	175±51	313±130	16±15	36±22	206±209

* Correction for presence of tree roots.

4.2 The ground layer

The vegetation type that had the largest ground layer biomass was the thin soil type closely followed by the mire (Table 4-3, 4-4). This pattern was not manifested in the NPP values where the thin soils had the highest NPP in Forsmark, while the mire was most productive in Oskarshamn. The grassland in Forsmark and the forested wetland and the shore in Oskarshamn lacked a ground layer, whereas the herb dominated moist soil at both sites had the lowest NPP estimates. The ground layer biomasses were generally higher in Forsmark, while the NPP was higher in Oskarshamn.

Unfortunately, all the cranked wire samples on the mire in Oskarshamn were destroyed. Instead, the Sphagnum estimates from the bedrock habitat in Forsmark were used also for Oskarshamn.

Lichens were only present in any significant proportions in the bedrock vegetation type, represented by species from the Cladonia subsection Cladina. Even here it was only dominating in one of the five squares in Forsmark and Oskarshamn.

Table 4-3. Ground layer parameters estimated in Forsmark. Mean values for biomass and NPP for different fractions of the ground layer in Forsmark. 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
Bryophyte biomass ($gdwm^{-2}$)	616±132	85±89	57±73	0	76±32	525±421
Lichen biomass ($gdwm^{-2}$)	0	<1	0	0	<1	98±219
Tot biomass ($gdwm^{-2}$)	616±132 458–772	85±89 0–216	57±73 5–167	0	76±32 30–118	623±317 240–1,105
Dominating species and their total coverage (dm^2)	Brown mosses	*P schreberi* (3.9), *D majus* (5.6)	*R triquetrus*	–	*R triquetrus*	*Sphagnum* (19.0), *P schreberi* (2.0), *D polysetum* (0.4), *Cladonia stellaris*, *C arbuscula*
Tot. coverage (dm^2)	31.3	9.5	3.8	0	15.4	21.4
Mean tot. coverage per square (%)	100	30	12	0	49	68
Comment		Prod for *P schreberi* from spruce forest in Oskarshamn	Prod. from spruce forest			Prod for *D polysetum* from bedrock in Oskarshamn
Bryophyte NPP ($gdwm^{-2}y^{-1}$)	20	15±11	4±7	0	15±9	95±58
Lichen NPP ($gdwm^{-2}y^{-1}$)	–	–	–	–	–	11

Table 4-4. Ground layer parameters estimated in Oskarshamn. Mean values for biomass and NPP for different fraction of the ground layer in Oskarshamn. 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
Bryophytes (gdwm^{-2})	219±137	<1	52±53	46±31	122±93	292±124	0
Lichens (gdwm^{-2})	1±1	0	<1	<0.1	1±1	134±126	0
Tot biomass (gdwm^{-2})	220±137 0–22	<0.1	52±53 10–139	46±31 7–86	123±93 33–266	426±118 269–541	0
Dominating species and their total coverage (dm^2)	*Sphagnum*	–	*P schreberi, Brachythecium sp, R triquetrus, D scoparium/ fuscescens*	*R squarrosus*	*Brachythecium sp* (7.75), *Sphagnum sp* (6.1), *Athricum sp* (5.5 dm^2), *P schreberi* (1.75), *Dicranum ful/ scop* (1.5 dm^2, *Polytrichum commune* (2.4)	*Dicranum polysetum* (12.5), *P schreberi* (11.4), *Claddonia arbuscula*	–
Tot. coverage (dm^2)	26.4	0	8.8	9.9	25.0	23.9	0
Mean coverage per square (%)	64	0	28	91	83	76	0
Comment	Prod for Sphagnum from bedrock in Forsmark		*R triquetrus* from Spruce forest, *Brachythecium* sp is set equal to *P schreberi*, *D scop/ fusc* from *D spurium* at bedrock	Prod from deciduous forest	Prod for *Sphagnum* from Forsmark, *D ful/scop* from *D polysetum*	Prod for *P schreberi* from bedrock Forsmark	
Bryophyte NPP (gdwm^{-2}y^{-1})	91±65	0	14±17	76±7,5	78±39	25±10	0
Lichen NPP (gdwm^{-2}y^{-1})	–	–	–	–	–	15	

4.3 The litter layer

The amount of litter was highest in the spruce forest (highest in Oskarshamn and second highest in Forsmark), Table 4-5, 4-6. The vegetation type with the lowest amount of litter was the mire.

Table 4-5. Litter layer parameters estimated in Forsmark. Standard deviation is presented after the mean and the range is presented below the mean. All numbers have the unit gdwm⁻².

Parameters	Mire	Forested wetland	Herb dominated moist soil	Grassland	Coniferous forest	Thin soil
Weight	539±212	698±277	1,081±861	980±286	1,042±488	595±430
	369–791	339–1,093	133–2,119	639–1,431	408–1,704	164–1,163
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 4-6. Litter layer parameters estimated in Oskarshamn. Standard deviation is presented after the mean and the range is presented below the mean. All numbers have the unit gdwm⁻².

Parameters	Mire	Forested wetland	Herb dominated moist soil	Grassland	Coniferous forest	Thin soil	Shore
Weight	272±197	1,084±248	489±169	486±449	1,595±1,083	1,216±543	700±305
	71–517	814–1,331	319–665	131–1,264	501–2,860	461–1,782	234–1,034
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*

4.4 Bryophyte species and NPP

The highest NPP estimates were found in Polytrichum commune in a spruce forest in Oskarshamn and in Sphagnum on bedrock in Forsmark (Table 4-7, 4-8). Sphagnum growing in hollows (N = 2) and at an intermediate position (N = 1) had twice the length increase than those on hummocks (N = 2), but the shoot abundance was instead twice the shoot abundance in hollows, equalling the total NPP per surface unit.

4.5 Total biomass and NPP

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 4-9, 4-10). These were also the habitats that displayed the highest biomass values. The lowest NPP was found in the forested wetland and the coniferous forest.

Table 4-7. NPP estimates for the bryophyte species investigated in Forsmark. The NPP estimate is up-scaled from dm^2 to m^2. The number of shoots is the actual number of the species followed and measured during a season, and replicates is the number of spots that were investigated within the vegetation type. Mean and min-max interval are calculated using the means of the replicates in the last column.

Latin name	Swedish name	Veg type	NNP Mean gdw $y^{-1}m^{-2}$	NNP min–max gdw $y^{-1}m^{-2}$	Shoots	replicates
Several species	Brunmossa	Mire	20	3–45	20	5
Sphagnum sp	Vitmossa	Thin soil	141	139–141	–	5
Rhytidiadelphus triquetrus	Kranshakmossa	Coniferous forest	31	5–56	24	5
Dicranum majus	Stor kvastmossa	Forested wetland	31	29–33	9	2
Climacium dendroides	Palmmossa	Forested wetland	12	1–14	10	2
Pleurozium schreberi	Väggmossa	Thin soil	20	–5–41	18	4

Table 4-8. NPP estimates for the moss species investigated in Oskarshamn. The NPP estimate is up-scaled from dm^2 to m^2. The number of shoots is the actual number of the species followed and measured during a season, and replicates is the number of spots that were investigated within the vegetation type. Mean and min-max interval are calculated using the means of the replicates in the last column.

Latin name	Swedish name	Veg type	Mean gdw $y^{-1}m^{-2}$	min–max gdw $y^{-1}m^{-2}$	Shoots	replicates
Pleurozium schreberi	Väggmossa	Herb dom. moist soil	56	34–125	13	3
Rhytidiadelphus squarrosus	Gräshakmossa	Herb dom. moist soil	84	64–104	8	2
Polytrichum commune	Björnmossa	Coniferous forest	216	148–285	10	2
Atrichum sp	Sågmossa	Coniferous forest	54	–	5	1
Pleurozium schreberi	Väggmossa	Coniferous forest	72	40–115	10	3
Dicranum polysetum	Vågig kvastmossa	Thin soil	40	21–55	20	4

Table 4-9. The mean total biomass and NPP of the field and ground layer for the investigated vegetation types in Forsmark. Biomass value in unit $gdwm^{-2}$ and NPP in unit $gdwm^{-2}y^{-1}$. 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	4,371±2,203	295±109	225±108	833±186	503±203	1,141±387
	2,718–7,816	180–471	118–392	659–1,147	219–720	715–1,697
NPP	505±118	32±25	195±106	825±246	137±78	465±335
	353–678	2–65	98–350	538–1,129	34–223	109–1,012

Table 4-10. The total biomass and NPP of the field and ground layer for the investigated vegetation types in Oskarshamn. Biomass value in unit gdwm^{-2} and NPP in unit gdwm^{-2}y^{-1}. 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	2,905±837	685±696	405±255	968±342	668±296	627±69	2,628±1,300
	1,744–3,991	44–1834	200–842	653–1,517	392–1,030	553–705	1,125–4,365
NPP	683±403	86±84	277±71	545±202	101±55	94±34	310±314
	303–1,367	34–234	213–396	268–792	44–182	56–142	55–753

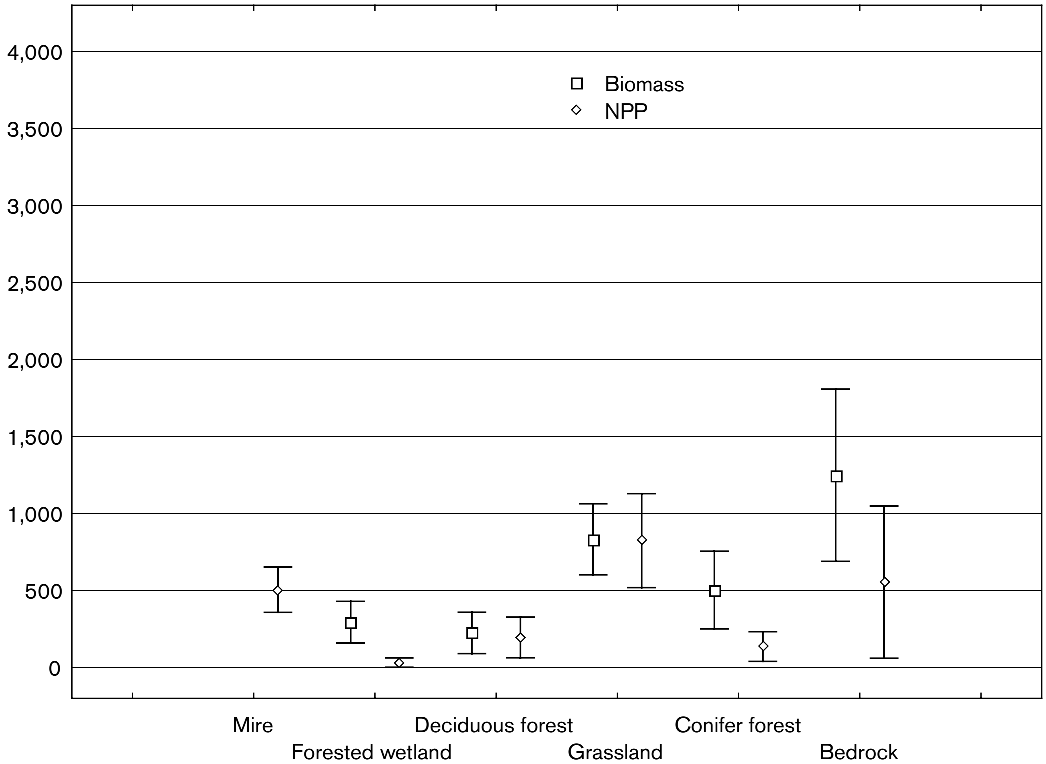

Figure 4-1. *Total biomass and NPP for the field and ground layer in the vegetation types investigated in Forsmark. The central value is the mean, while bars show the 95% confidence interval. The mean and bars describing biomass for the mire were excluded from the figure (mean 4,371 gdwm^{-2}). Units are in gdwm^{-2} for biomass and in gdwm^{-2}y^{-1} for NPP.*

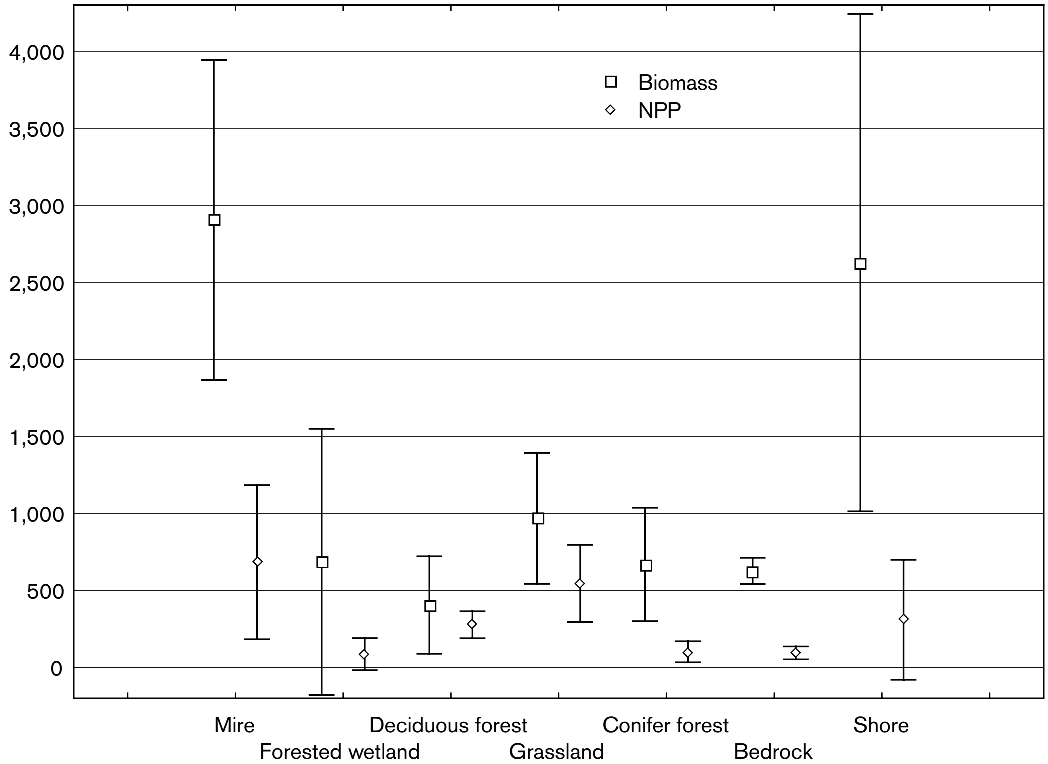

Figure 4-2. *Total biomass and NPP for the field and ground layer in the vegetation types investigated in Oskarshamn. The central value is the mean, while bars show the 95% confidence interval. Units are in gdwm^{-2} for biomass and in gdwm^{-2}y^{-1} for NPP.*

5 Discussion

5.1 The field, ground and litter layers

A comparison with an earlier study conducted in Forsmark /Fridriksson and Öhr, 2003/ and a study made in Knottåsen /Berggren et al. 2004/ not far from Forsmark, but further inland, reveals a large variation (Table 5-1). The most deviant value was found in the earlier study from Forsmark and is explained by an extremely abundant moss layer in the young spruce forest that was sampled.

A comparison of the data from Oskarshamn shows similar values as for the coniferous forest, but quite different compared to the mean for the dry forest in Asa (Table 5-2, an inland locality not far from Oskarshamn, /Berggren et al. 2004/). This deviation may be explained by the bedrock habitat that has a rather thin or non-existing soil layer and a sparse Scots Pine tree layer. A sparse or non-existing canopy implies a more abundant field and/or ground layer. This is the most abundant vegetation type in the Oskarshamn area.

Few data are available covering the below-ground biomass and NPP for herbs and grasses, and this part is therefore left without comparison.

Table 5-1. A comparison of the biomass above ground in the field and ground layer in two studies of similar vegetation types from the same latitude in Sweden. All units are in gdwm^{-2}.

Vegetation type	This study (Forsmark)	Earlier study (Forsmark)[1]	Knottåsen[2]
Thin soil	866	1,030	437*
Coniferous forest	117	968	255
Mire	798	542	–

[1)] /Fridriksson and Öhr, 2003/.
[2)] /Berggren et al. 2004/.
* Norway spruce dominates, but dry conditions.

Table 5-2. A comparison of the biomass above ground in the field and ground layer in a study /Berggren et al. 2004/ of similar vegetation types from the same latitude in Sweden. All units are in gdwm^{-2}.

Vegetation type	This study (Oskarshamn)	Asa
Thin soil	481	175*
Coniferous forest	132	159

* Norway spruce dominates, but dry conditions.

A comparison of NNP between sites reveals a fairly consistent pattern of the relative order of vegetation types, e.g. those vegetation types with high or low relative values are the same in both Forsmark and Oskarshamn. In a direct comparison of the values between sites Oskarshamn has a higher NPP in the mire, the forested wetland and the herb dominated moist soils, while Forsmark demonstrates a higher NPP in the grassland, coniferous forest and the thin soils on bedrock. /Berggren et al. 2004/ found that the biomass increased in their Norway spruce forests with a gradient towards north, which seemed to be related to an opposite trend in tree biomass. Such a tree biomass pattern was not found for Oskarshamn compared to Forsmark /Lindborg (ed), 2005a,b/ and neither an opposite relationship for the biomass of the field and ground layer compared to the tree layer.

The presence of grazing at one site in Forsmark (deciduous forest) and one in Oskarshamn (grassland) entails underestimation of the actual values of biomass and NPP. The magnitude of this underestimation is difficult to estimate, but a look in Table 4-9 and 4-10 suggests that the underestimation is largest in the deciduous forest in Forsmark.

The sample size covering each vegetation type locality is small. However, this is a minor problem compared to the lack of replicates within vegetation types between localities. This means that we do not know how large the variation is within the same vegetation type between localities. Few such studies have been done over a larger regional area, but the fairly consistent pattern between vegetation types in Forsmark and Oskarshamn does anyway give a hint about their relative order.

The vascular plant material that had died during the year was not estimated separately but added to the litter layer in this study, which means that the NPP values are an underestimate of the actual NPP. This underestimation is probably proportional to the actual vascular plant NPP, meaning that the actual underestimation is larger in those vegetation types with a high vascular plant NPP, such as the grasslands.

A large variation, that in some cases is manifested in a standard deviation below zero, indicates that sample sizes should be larger, alternatively that the assumption of a normal distribution is violated. This study has focused on covering the major soil and soil type categories that dominate in the area. The spatial variation is very much a function of topography and climate that may be variable on both intermediate and small spatial scales, e.g. north facing slopes, hollows etc. This variation is therefore difficult to cover even with a large and time consuming experimental setup.

This study has not been able to quantify the temporal variation, which may be considerable depending on the variation in annual climate properties, such as precipitation. The year 2004 was somewhat warmer then the mean (of 1961–1990) for both Forsmark (+0.8°C) and Oskarshamn (+1.2°C), but the total precipitation was normal for both sites /SMHI, 2004/. However, the summer is considered to be wetter than usual. The spring did arrive about two weeks earlier than normal in Forsmark and as usual in Oskarshamn. Overall, the weather must be considered to be rather normal lacking any extreme conditions that would bias the biomass and NPP estimates.

This investigation has not quantified the amount of mycorrhizal fungi and mycelia present in the soil. Several of the vascular plants species are known to be associated with mycorrhizal fungi, e.g. species belonging to *Ericaceae* /Read, 1994/. This is also true for the vegetation types with a tree layer. The presence of mycorrhizal fungi in the soil have implications both for the biomass and the NPP, and may be added using generic values from the few studies that have been done, e.g. /Wallander et al. 2001; Wiklund et al. 1994; Vogt et al. 1982/ who present figures for ectomycorrhizal fungi in a *Picea* forest community.

5.2 Bryophytes

/Rühling, 1985/ reported a mean annual biomass increase of 116±14 $gdwm^{-2}$ yr^{-1} for *Hylocomium spendens* in southern Sweden, while Finnish populations of *P schreberi* increased with 98 $gdwm^{-2}yr^{-1}$ /Pakarinen and Rinne, 1979/. The estimated values from Forsmark and Oskarshamn are lower, although the range includes their values. NPP of bryophytes is decreasing when going north, e.g. /Zechmeister, 1998/, but this is not sufficient to explain the low value from the bedrock type in Forsmark. In that vegetation type, a more possible explanation is that the exposed bedrock in combination with the summer heat may change the vegetation period and increase the importance of early spring and late autumn for the NPP. Our measurements are also only covering the normal vegetation period, implying that the moss NPP is slightly underestimated.

A short compilation by /Rochefort et al. 1990/ of NPP estimates for *Sphagnum fuscum* from mires in the Nordic countries showed an interval range from 70–290 $gdwm^{-2}y^{-1}$. The large interval covers the value from the bedrock and justifies the use of that value in the mire in Oskarshamn.

5.3 Concluding remarks

The aim of this study was to estimate the biomass and NPP for the dominating vegetation types at the two sites Forsmark and Oskarshamn during a limited time with a limited setup. Although the variation in estimated parameters is relatively large, the study seems to give an acceptable description of the field, ground and litter layer properties at the two sites, under given circumstances. No published studies have quantified and presented values that cover the whole range of properties for several different vegetation types as described here, so this will serve as an acceptable base for further investigations and calculations in order to build site descriptive ecosystem models.

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Appendix 1

Primary data from the sample plots

Uncorrected raw data from the 0.25×0.25 m sampling plots scaled to gram dry weight per square metre.

Site	Locality	Sample	Shrub Wood g dw/m²	Shrub Wood, this year g dw/m²	Shrub Green g dw/m²	Shrub Green, this year g dw/m²	Shrub Fruits g dw/m²	Shrub Dead g dw/m²	Field layer g dw/m²	Moss g dw/m²	Lichen g dw/m²	Litter g dw/m²	Roots g dw/m²
Forsmark	1	1							172.560	527.104		791.136	2,017.856
	1	3							145.440	771.712		368.576	2,158.624
	1	5	46.240	31.984	3.232	34.096			94.240	725.440		372.400	4,412.720
	1	6	8.128	2.528		7.728			100.880	457.984		748.032	2,318.880
	1	9	43.104	8.160		26.656			184.672	596.176		412.624	6,956.800
	2	1							2.080	52.336		699.424	
	2	3							10.592	22.800	0.464	575.712	1,149.328
	2	5							0.656	0.000		1,092.928	472.096
	2	6							4.112	131.392	2.176	781.504	310.784
	2	9							12.160	216.144	0.816	338.928	209.856
	3	1		5.296		3.840			29.664	9.952		2,118.512	351.488
	3	3							32.608	4.896		1,285.968	212.608
	3	5				1.680			109.776	166.640		262.768	298.432
	3	6	5.648	2.816		1.792			47.280	5.584		1,605.632	
	3	9	4.976	4.400	3.472				80.800	97.664		132.800	202.192
	4	1							237.280			1,431.296	421.744
	4	3							238.480			967.792	509.168
	4	5							179.296			639.312	622.192
	4	6							343.104			972.464	467.648
	4	9							376.320			889.376	771.024

Site	Locality	Sample	Shrub Wood g dw/m²	Shrub Wood, this year g dw/m²	Shrub Green g dw/m²	Shrub Green, this year g dw/m²	Shrub Fruits g dw/m²	Shrub Dead g dw/m²	Field layer g dw/m²	Moss g dw/m²	Lichen g dw/m²	Litter g dw/m²	Roots g dw/m²
	5	1							54.480	29.808		407.520	1,528.976
	5	3							23.680	66.560		1,212.048	339.344
	5	5							50.672	79.024	0.816	1,704.288	710.416
	5	6		4.080		1.536			60.560	86.976		766.192	1,491.488
	5	9							7.376	117.504		1,120.560	
	6	1		2.832		3.680			10.176	14.368	489.488	1,162.944	510.720
	6	3	55.936	28.896	234.064	83.344	2.608	14.464		698.112		198.704	638.656
	6	5	19.152	18.272	86.064	65.936	2.848	5.328		567.648	0.384	864.704	522.416
	6	6	32.224	77.872	90.288	56.112		1.024	165.648	239.456	0.256	585.856	814.656
	6	9	21.248	21.024	92.560	53.872	5.152	18.608		1,104.736		163.904	998.336
Oskarshamn	1	1							165.648	287.904		224.416	2,897.312
	1	3							152.592	274.576		71.344	1,316.464
	1	5	871.520	159.824	27.792	108.192		64.960	172.544	180.704	2.640	436.240	1,078.384
	1	6							101.056			516.784	2,671.280
	1	9	40.592	18.512	13.952	15.952			92.672	351.920		111.520	3,457.600
	2	1							78.016			1,100.304	1,141.504
	2	3							13.344			814.064	686.656
	2	5							22.064	1.408		1,331.264	1,944.016
	2	6							18.672	0.288		851.264	4,777.600
	2	9							11.312			1,325.600	85.984
	3	1							86.448	138.752		319.264	1,621.984
	3	3	8.176	2.448		9.280			58.768	9.648	0.528	664.752	425.264
	3	5							131.248	25.920		465.872	512.800
	3	6							82.736	17.200		661.392	264.224
	3	9		1.536		14.528			51.168	66.608	0.080	331.664	650.720
	4	1							235.952	25.584		330.208	447.408

Site	Locality	Sample	Shrub Wood g dw/m²	Shrub Wood, this year g dw/m²	Shrub Green g dw/m²	Shrub Green, this year g dw/m²	Shrub Fruits g dw/m²	Shrub Dead g dw/m²	Field layer g dw/m²	Moss g dw/m²	Lichen g dw/m²	Litter g dw/m²	Roots g dw/m²
	4	3							164.880	62.112		436.000	1,290.480
	4	5							123.552	49.456		269.424	828.320
	4	6							191.648	7.344		1,263.952	760.208
	4	9							65.424	85.504	0.304	131.008	502.208
	5	1							14.320	156.528		567.424	582.176
	5	3								56.976		1,535.632	940.544
	5	5								29.968	3.328	2,510.032	2,371.088
	5	6							14.112	102.256	0.768	500.976	2,401.760
	5	9	4.256	3.024	1.568	5.136			2.400	265.280	0.672	2,859.792	761.312
	6	1	8.608	14.288	49.232	20.912		2.032		267.040	2.816	1,570.096	495.472
	6	3	13.536		6.176	17.440				282.448	258.304	461.376	289.120
	6	5	4.752	2.976	12.464	2.480				106.448	243.600	858.480	511.984
	6	6	12.000	4.912	35.280	10.080				432.224		1,782.304	333.856
	6	9	5.968		34.096	8.912			8.000	371.360	167.360	1,406.528	288.752
	7	1							176.544			234.224	948.768
	7	3							18.432			827.712	2,927.776
	7	5							250.880			584.112	2,888.448
	7	6							28.112			819.664	1,538.288
	7	9							41.872			1,034.048	4,323.200