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Abstract

The objective of the present study was to measure the actual amount of carbon of the ground, field and shrub layers of the six different vegetation types at the area surrounding the Forsmark nuclear power plant. The project included collection of samples of plant biomass at the Forsmark test site for a long-term storage of nuclear waste material, and processing it in order to enable an assessment of the actual amount of carbon in the area. Of the six vegetation types within the Forsmark area, the *Pinus* dominated area had the largest total biomass, (average total biomass = 1621 g/m^2, SD. 330). However, regarding living biomass, the harvested and deliberately burned area had the largest value, (average living biomass = 1115 g/m^2, SD. 485) and can therefore be regarded as the largest carbon sink of the area in terms of $g{\bullet}C/m^2$ excluding epiphytes. Our values for biomass below ground are for the *Pinus* area only and amounted to 35% of the living biomass of the *Pinus* dominated area, (average 362 g/m^2, SD. 198). The laboratory analysis of carbon content gave a mean value of 45.3% C, SD. 1.3% n=26; and 734 $g{\bullet}C/m^2$ for the *Pinus* dominated area.

Contents

1 Introduction

The Forsmark site is in the hemiboreal zone /Ahti et al, 1968/. The vegetation at the site is predominantly a conifer evergreen forest with some limited deciduous spots mainly close to wetter areas. The rock foundation is fairly rich with water to a certain depth but not very porous in general.

A possible underground storage facility for nuclear waste materials sited in the Forsmark area could affect the ecosystem if a leakage of radionuclides from their protective capsules would occur. Therefore, the flow of groundwater is important since radionuclides would have to reach the surface by groundwater. The water consumption of the forest ecosystem is thus an important factor when making a model for a storage facility, when the model is to include the ecosystem. The amount of carbon bound in the forest ecosystem is an indicatior on how much water the ecosystem uses or needs by tapping into groundwater sources.

The objective of the present study was to measure the actual biomass both above and below ground in order to define the amount of carbon confined in the forest floors of the Forsmark site. The amount of carbon can give information about the actual size or capacity of the carbon sink which the forest floor ecosystem at Forsmark is, and can therefore yield information on how dynamic the ecosystem actually is.

The measuring of plant biomass above ground ($\mathbf{B_A}$) is relatively easily done. On the other hand, measurements of plant biomass below ground ($\mathbf{B_B}$) is harder since it includes removal of rootsystems from the surrounding soil. Methods for measuring the $\mathbf{B_B}$ are not so accessible since very few have actually done the measurements.

1.1 Material and methods

Data and methods are lacking due to two main factors: in previous studies they have been thought of as 1) laborious and too costly, and 2) controversial /Laurenroth et al, 1986; Publicover and Vogt, 1993; Nadelhoffer and Raich, 1992; Steele et al, 1997/. Belowground production in forests remains poorly understood due to method challenges and incomplete measurements /Clark et al, 2001/.

The assessment was done by using a plant species inventory previously done /Abrahamsson, 2003/ as a base for choosing sample plots. The project included six vegetation types /Abrahamsson, 2003/: a *Pinus* dominated area, a *Picea* dominated area, a wetland area, a seashore area, a newly harvested and burned coniferous area and a pasture area used for grazing of cattle, see Figure 1-1. The *Pinus* and *Picea* dominated areas do represent the main biotopes of the whole area, while the other four vegetation types are regarded as minor parts. All samples were collected in June 2003.

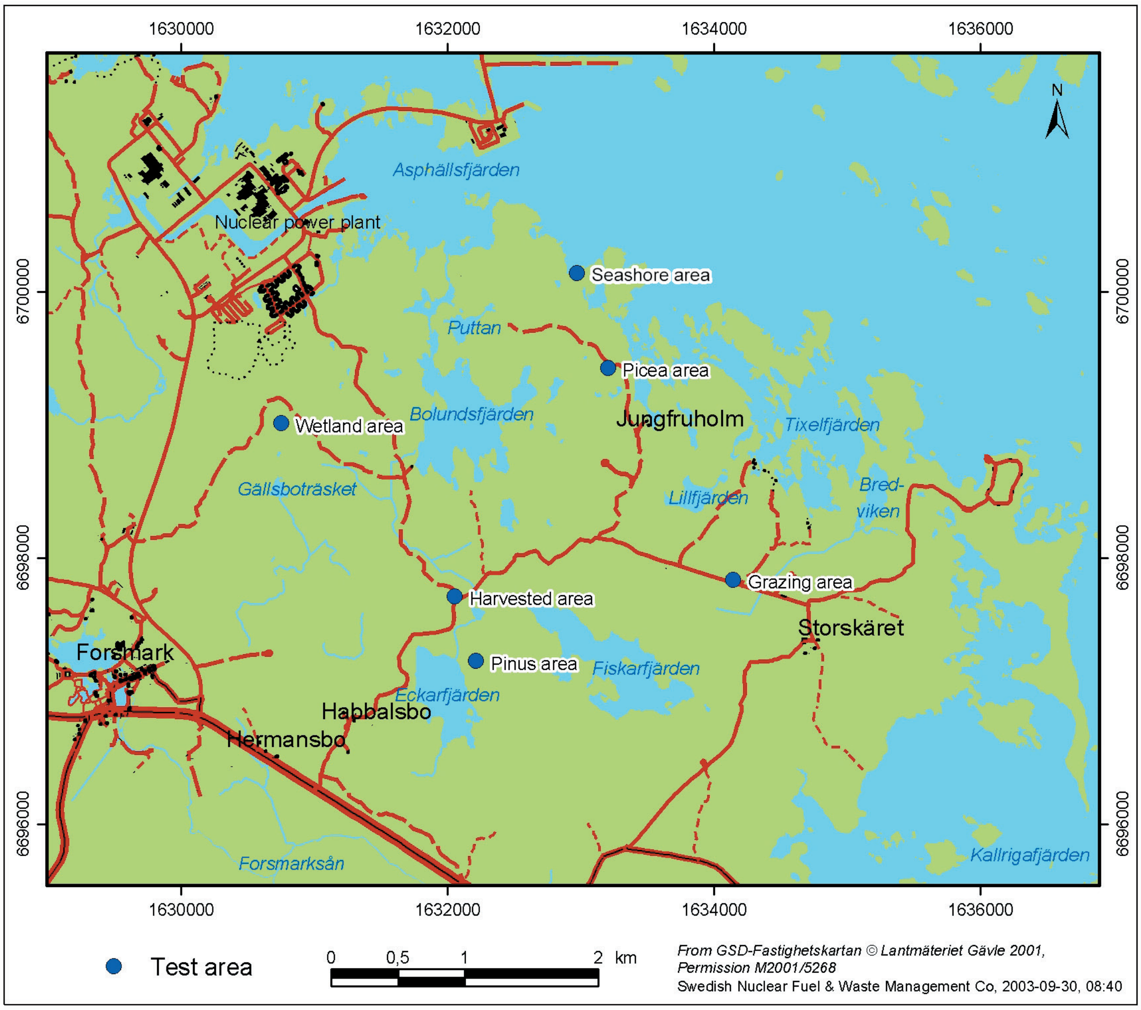

Figure 1-1. *Sampling sites in the Forsmark area.*

At each vegetation type a base point was chosen which was marked by using the GPS. Using the base point of each vegetation type, six test plots were randomly chosen in the close nearby area two to three meters from the base point for the measurement of $\mathbf{B_A}$, and at the six test plots of the *Pinus* and *Picea* dominated areas the $\mathbf{B_B}$ was also collected. The forested areas were chosen for measurements of $\mathbf{B_B}$ since they represent the dominant vegetation of the area. The size of each test plot was 25x25 cm or 625 cm^2 surface area. The coverage of the different vegetation of different vegetation layers was estimated visually at each test plot. The dominant species at each test plot was identified, both living and the dead/litter.

To measure the $\mathbf{B_A}$, all vegetation (dead and alive) was cut down on each test plot to the ground. Three vegetation layer categories were used: ground layer, field layer and shrub layer. Within these categories all biomass was separated into green, brown and dead/litter. Green biomass was categorized as the actual growth of the year, brown biomass was categorized as all living biomass else than the growth of the year and the litter was categorized as dead material above and within the ground layer. The harvested plants were dried in ovens at the Botanic institute of the Stockholm University until the weight of the biomass was stable. The temperature chosen for drying was 70°C. The dry weight of organic matter was converted to amount of carbon, in the form of gC/m^2. Samples were weighed to the nearest mg.

To measure the $\mathbf{B_B}$ the root zone was dug up at the six 25x25 cm or 625 cm^2 surface area test plots of the *Picea* and *Pinus* dominated areas. It was assumed that the root zone would be limited to a maximum depth of 40 cm. Before digging, the test plots had already been cleared of all above ground vegetation as well as litter. The dug up clumps of soil and roots was then measured for depth of root zone. All tree roots were separated from the samples since biomass belonging to epiphytes was to be excluded. Thereafter the soil was rinsed from the root mass with water and a 1 mm^2 metal mesh sieve. Aside from the *Pinus* dominated area, we only collected a single sample of biomass below ground in the *Picea* area. The other plots within the *Picea* area did not harbour any vegetation other than bryophytes. As with the $\mathbf{B_A}$, the roots were dried in ovens at the Botanical institute of the Stockholm University untill the weight of the biomass was stable. The drying temperature was set at 70°C. When using quotas, the dry weight of organic matter was converted to amount of carbon, in the form of g•C/m^2. After drying, the rootmass was sieved again with a 1 mm^2 metal mesh sieve to clear remaining soil that was fastened to the roots after the first sieving. Samples were weighed to the nearest mg. The procedure of drying took from 24 to 48 hours for each batch , likely since the samples were quite moist and the small size of the oven allowed only a small part of the samples to be treated at once. The samples waiting to be dried were freezed and kept frozen untill they could be dried in order to lose as little carbon as possible to microbial respiration.

When defining the carbon level in forest ecosystems, the usual method in previous studies is to use a quota of 0.4 to 0.5 when regarding living plant biomass and a quota of 0.3 to 0.4 when regarding litter or dead material /Gower et al, 2001; Smith and Heath, 2002; Kätterer, 2003; King, 2003/. We wanted to obtain as good results as possible and therefore the margin of error of 20 to 25% when using quotas was considered to high to be acceptable. We did though include calculations of the amount of carbon (see Table 1-3.) with the already given different quotas for comparison. In the present study, the value for biomass below ground was 35% of the total living biomass in the *Pinus* area which is similar to results from previous studies regarding woody species /Clark et al, 2001/, /Jackson et al, 1997/ and /Price et al, 1999/. We wanted to take root samples from every test plot within the forested areas but since the *Picea* dominated area was nearly devoid of all but bryophytes, there was a single root sample we could dig up there. As mentioned before, this may not affect the values for the actual biomass of *Picea* dominated areas within the region but is no definite description of the vegetation type in general.

As the experiment progressed, we saw some things that might need some adjustment in future studies. The biggest issue was without doubt the sample collection in the forested areas. The forest floor was quite different from place to place, from being totally bryophyte dominated into being a more mixed ground, field and shrub flora. The diversity between different forested areas has probably much to do with different levels of soil humidity and pH. Therefore it would be of interest to collect samples from more than only one *Pinus* area and one *Picea* area to compensate for the diversity and even some soil samples to analyze the pH level. While our designated Coniferous dominated test areas may not give a false image of the actual biomass of the forest floors of the Coniferous dominated areas in whole, they certainly do not describe the actual floral image of the forest floors of the forested areas of the region in general. Our designated *Picea* test area had a forest floor that was totally dominated by bryophytes whereas other areas dominated by *Picea* were not. Our designated *Pinus* area had more of a mixed species forest floor and may represent the actual identities of a typical Pine forest in the region. A future study might even concentrate on the forested areas since the other ones in this study do not represent the dominant biotopes, but are only a smaller part of the whole local ecosystem. Our tight schedule did unfortunately not allow for more sampling to be done.

Laboratory analysis was performed by the Department of soil sciences at the Uppsala University using the Dry burning method /Zaar, 2003/ to obtain values for carbon.

All data was treated statistically with the software Statistica 6.0.

1.2 Results

The results from the procedure of drying and weighing were as follows.

Table 1-1. The average biomass of the 6 vegetation types in g/m² (n=6).

	Harvested area	Pasture	Seashore	Wetlands	*Pinus*	*Picea*
Total biomass g/m² (average)	1509	426	561	1265	1621	1303
SD $_{\text{Total biomass}}$	423	192	99	297	331	451
Living biomass g/m² (average)	1115	356	257	542	1030	968
SD $_{\text{Living biomass}}$	486	211	159	180	255	348
Litter g/m² (average)	394	118	304	723	590	334
SD $_{\text{Litter}}$	339	90	202	245	187	253
Biomass B_B g/m² (average)					362	(48)

Table 1-2. Laboratory analysis for the *Pinus* dominated area, all values are given in percentage (n=24). The analysis gives an average of 734 g•C/m² for total biomass in the *Pinus* area.

	The 6 test plots within the *Pinus* area (%)					
Pinus	**1**	**2**	**3**	**4**	**5**	**6**
Fieldlayer green	45.42	46.66	45.93	46.09	46.34	45.93
Fieldlayer brown	44.60	46.58	45.61	46.51	46.37	44.53
Groundlayer	44.05	42.30	42.33	44.98	45.11	44.44
Litter	45.34	46.21	46.35	46.81	46.11	46.15

Table 1-3. The average amount of carbon in the 6 vegetation types, litter and living biomass with different quotas (Q) for comparison in g•C/m² (n=6).

	Harvested area	Pasture	Seashore	Wetlands	*Pinus*	*Picea*
Carbon g/m² (Q = 0.3) $_{\text{litter}}$	118	36	91	217	177	100
Carbon g/m² (Q = 0.4) $_{\text{litter}}$	158	47	122	289	236	134
Carbon g/m² (Q = 0.4) $_{\text{living b.}}$	446	142	103	217	412	388
Carbon g/m² (Q = 0.5) $_{\text{living b.}}$	558	178	128	271	515	484

Total biomass was high in the harvested area, the wetlands area and the *Pinus* and *Picea* dominated areas, but fairly low in the pasture and seashore areas (Table 1-1). A similar pattern was observed for the living biomass (Table 1-1), with the exception of wetland area, which had a comparatively low living biomass.

Tables 1-1, 1-2 and 1-3 as well as Figures 1-2 and 1-3 are a summary of all raw data collected in the experiment. The original figures from the fieldwork are available in Appendix 1. All figures are for dry weight in grams.

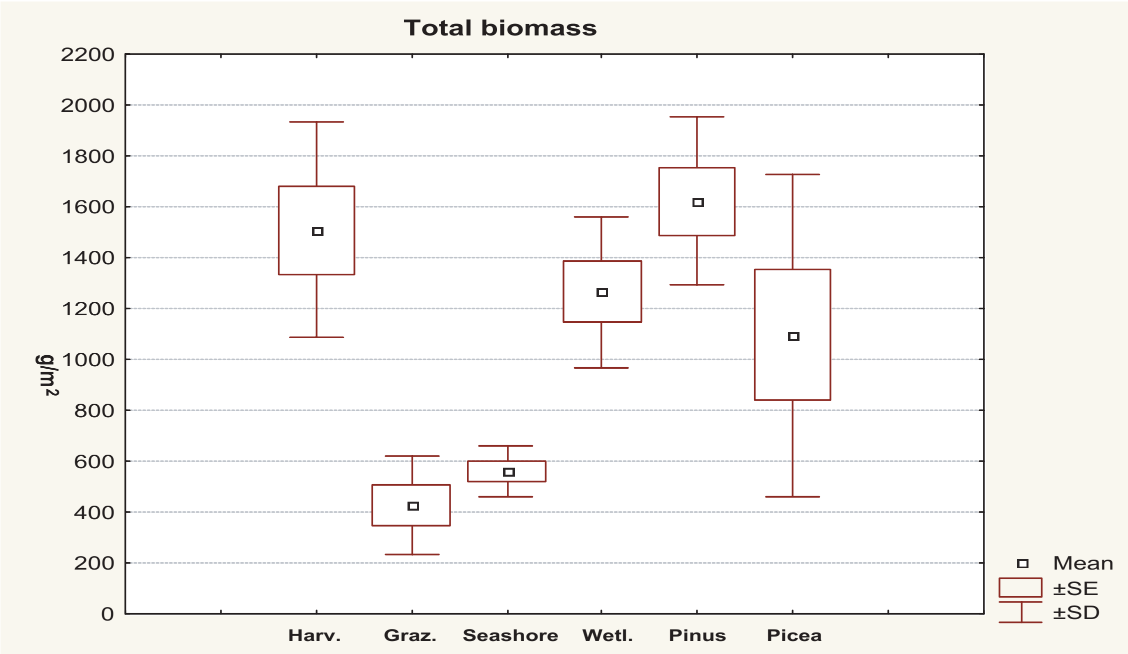

Figure 1-2. *The total biomass of the six test areas in grams/m*^{2}.

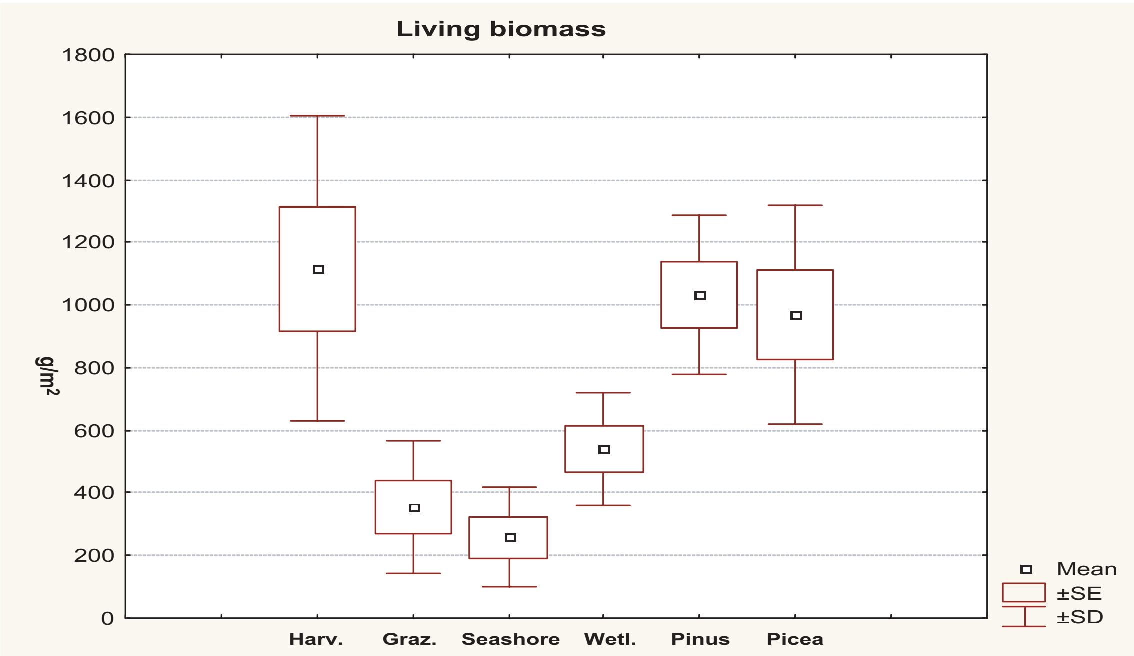

Figure 1-3. *The living biomass of the six test areas in grams/m*^{2}.

1.3 Discussion

As would perhaps be expected, the vegetation type with the largest living biomass of the six was the newly harvested and deliberately burned one. Vegetation growing in a harvested and deliberately burned area can be regarded as early succession since the area is almost void of any competitors /Krebs, 2001/. In other forest floor areas the growth is likely hampered by competition and even shortage on light as can be expected when secondary succession occurs. In a harvested and deliberately burned area, nutrients are abundant due to the previous burning and there is no shortage on light and likely not water since all epiphytes had been removed by harvesting equipment. Of the non-forested areas, the composition of species in the harvested area was by far the simplest of all, with *V.myrtillus* utterly dominating in most of the test plots. This phenomenon supports the theory of primary succession. Burning newly harvested areas might therefore be positive from the CO_2 binding perspective since it encourages primary succession and biomass production.

The presence of herbivores is the most likely reason for the pasture being fairly low in total biomass as grazing is seldom lethal to plants but merely a regulating factor /Krebs, 2001/.

Having contact with the Baltic Sea is likely the dominant factor for the seashore area having a comparatively low total biomass since both the constant wetness and salinity affect the proliferation of plants as grasses /Barrett-Lennard, 2003; Koslowski, 1997/.

The wetlands were utterly dominated by Common reed (*P.Australis*) which grew to 1.5 to 2 meters tall and in thickets, thus likely outcompeting other species along with the unfavorable situation of constant wetness /Lenssen et al, 2000/.

The *Pinus* and *Picea* dominated areas were not so different from one another regarding total biomass. The dominant forest floor flora in the *Picea* area consisted exclusively of bryophytes likely due to their resistance to low pH produced by shed coniferous needles. The forest floor of the *Picea* area might on the other hand be considered to be far more stable since it harboured almost exclusively bryophytes (Sphagnum). In the long run, those sphagnum rich areas are likely to become more productive than the harvested area since the sphagnum is competitive and places as little demand on the environment as it does. The *Pinus* area had far more diversity in plant species most likely due to the fact that it was not as dense as the *Picea* area was, posing less interspecific competition on other species. The *Pinus* dominated area proved to have the largest total biomass of the six test areas, but only when including the values for $\mathbf{B_B}$ or biomass below ground.

The whole Forsmark area is dominated by evergreens as said earlier and the spots chosen for *Pinus* sampling can be regarded as representative for the forest floor vegetation.

As mentioned earlier, in previous studies quotas have been used as a measurement for carbon in vegetation, the quotas ranging from 0.4 to 0.5 /Gower et al, 2001; Smith and Heath, 2002; Kätterer, 2003; King, 2003/. The laboratory analysis does support this, giving a mean carbon value of 45.3%, SD. 1.3% of the samples from the *Pinus* dominated area. However, it is of interest to see that there is no real difference in carbon content between living biomass or litter which is contradictory to earlier studies regarding litter as having less carbon than living biomass /Gower et al, 2001; Smith and Heath, 2002; Kätterer, 2003; King, 2003/. The reason for this is not quite clear since microbial effect should be negative on carbon content in litter.

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Kätterer T, 2003. Professor. Soil fertility and plant nutrition, Uppsala University Department of soil services. Personal comments.

Zaar M, **2003.** Uppsala University Department of soil services. Personal comments.

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Appendix 1

The following tables show the values for each test area and each test plot within the test areas. All values are in grams (g) and represent dry weight. All test plots are of the typical size of 25x25 cm or 625 cm^2. The biomass is divided into the three original categories which were green, brown and dead/litter. The tables contain the different forest floor vegetation layers which were bottom, field and shrub layer. The tables include the dominant species on each test plot.

Table A-1. Harvested area: (O-1632057, N-6697713)

		1	2	3	4	5	6
Groundlayer	Weight	19.643 g	74.480 g	88.648 g		17.707 g	39.650g
	Dominant vegetation	Bryophytes 75%	Bryophytes 75%	Bryophytes 75%		Bryophytes 25%	Bryophytes 25%
Fieldlayer	Weight total	33.503 g	22.261 g	8.092 g	14.350 g	13.356 g	38.755 g
	Green	22.362 g	14.668 g	7.495 g	14.350 g		30.058 g
	Brown	11.141 g	7.539 g	0.597 g			8.697 g
	Dominant vegetation	V.myrtillus 75%	V.myrtillus 75%	V.myrtillus 75%	V.myrtillus 50%	Grasses 12.5%	Grasses 50%
Shrublayer	Weight total				2.863 g	45.155 g	
	Green				1.395 g	30.359 g	
	Brown				1.468 g	14.796 g	
	Dominant vegetation				R.idaeus 12.5%	R.idaeus 100%	
Litter	Weight	63.929 g	2.695 g	17.159 g	26.964 g	24.793 g	12.147 g
	Depth	1.0 cm	<0.5 cm	0.5 cm	1.0 cm	<0.5 cm	<0.5 cm
	Dominant vegetation	Grasses	Grasses	Grasses	Grasses	Grasses	Grasses
Biomass (living)		53.146 g	96.741 g	96.740 g	17.213 g	76.218 g	78.405 g
Biomass total		117.075 g	99.436 g	113.899 g	44.177 g	101.011 g	90.552 g

Table A-2. Grazing area: (O-1634144, N-6697838)

		1	2	3	4	5	6
Groundlayer	Weight	8.68 g	3.20 g	8.464 g	1.498 g		
	Dominant vegetation	Bryophytes 12.5%	Bryophytes 12.5%	Bryophytes 30%	Bryophytes 12.5%		
Fieldlayer	Weight total	15.753 g	10.581 g	39.005 g	11.080 g	14.697 g	20.555 g
	Green	14.751 g	10.581 g	22.359 g	11.080 g		
	Brown	0.984 g		16.646 g			
	Dominant vegetation	Grasses 90%	Grasses 90%	Grasses 90%	Grasses 90%	Grasses 90%	Grasses 50%
Litter	Weight	6.579 g	6.355 g	17.855 g	1.364 g	4.013 g	8.144 g
	Depth	0.5 cm	0.5 cm	0.5 cm	0.5 cm	0.5 cm	0.5 cm
Biomass (living)		24.433 g	13.781 g	47.469 g	12.578 g	14.697 g	20.555 g
Biomass total		31.012 g	20.136 g	47.469 g	13.942 g	18.710 g	28.699 g

Table A-3. Seashore area: (O-1632975, N-6700138)

		1	2	3	4	5	6
Groundlayer	Weight				3.864 g		26.468 g
	Dominant vegetation				Bryophytes 75%		Bryophytes 90%
Fieldlayer	Weight total	5.366 g	16.835 g	10.058 g	7.693 g	9.002 g	4.625 g
	Green	5.366 g	16.835 g	10.058 g	7.693 g	9.002 g	4.625 g
	Brown						
	Dominant vegetation	Grasses 60%	Grasses 70%	Grasses 50%	Grasses 25%	Grasses 90%	J.gerardi 75%
Shrublayer	Weight total				12.467 g		
	Green				9.961 g		
	Brown				2.506 g		
	Dominant vegetation				H.rhamnoides 50%		
Litter	Weight	22.933 g	18.672 g	34.614 g	4.486 g	29.259 g	4.108 g
	Depth	0.5 cm	0.5 cm	0.5 cm	0.5 cm	0.5 cm	0.5 cm
Biomass (living)		5.366 g	16.835 g	10.058 g	24.024 g	9.002 g	31.191 g
Biomass total		28.299 g	35.507 g	44.672 g	28.510 g	38.261 g	35.201 g

Table A-4. Wetlands: (O-1630753, N-6699011)

		1	2	3	4	5	6
Groundlayer	Weight Dominant vegetation	7.952 g	2.059 g Bryophytes 40%	9.792 g Bryophytes 100%	10.042 g Bryophytes 100%	7.655 g Bryophytes 100%	12.598 g Bryophytes 75%
Fieldlayer	Weight total Green Brown Dominant vegetation	5.653 g 5.653 g Carex 30%, P.australis 30%	29.712 g 29.712 g Carex 100%	33.048 g 33.048 g Carex 100%	25.088 g 25.088 g P.australis 30%	37.951 g 37.951 g P.australis 90%	21.717 g 21.717 g P.australis 12.5%, Carex 12.5%
Litter	Weight Depth	34.512 g 5 cm	47.005 g 5 cm	40.383 g 5 cm	59.154 g 2 cm	24.667 g 5 cm	65.583 g 5 cm
Biomass (living)		13.605 g	31.771 g	42.840 g	35.130 g	45.606 g	34.315 g
Biomass total		48.117 g	78.776 g	83.223 g	94.284 g	70.273 g	99.898 g

Table A-5. *Pinus* area: (O-1632217, N-6697226)

		1	2	3	4	5	6
Groundlayer	Weight Dominant vegetation	9.472 g Bryophytes 90%	24.758 g Broyphytes 75%	65.304 g Broyphytes 75%	63.662 g Bryophytes 90%	26.582 g Bryophytes 90%	23.556 g Broyphytes 75%
Fieldlayer	Weight total Green Brown Dominant vegetation	11.768 g 9.105 g 2.663 g V.myrtillus 50%	3.578 g 2.780 g 0.798 g V.vitis-idaea 75%	2.559 g 1.732 g 0.827 g V.vitis-idaea 12.5%, V.myrtillus 12.5%	4.923 g 3.897 g 1.026 g V.vitis-idaea 50%	2.128 g 1.591 g 0.537 g V.vitis-idaea 25%	12.264 g 8.331 g 3.933 g V.vitis-idaea 50%, V.myrtillus 25%
Litter	Weight Depth	55.315 g 2 cm	31.371 g 2 cm	44.471 g 2 cm	26.289 g 2 cm	25.171 g 2 cm	38.895 g 2 cm
	Comp.	*Pinus* originated needles, sticks and cones as well as some birchleaf					
Root zone	Weight Depth	34.190 g 10 cm	30.427 g 3 cm	10.395 g 5 cm	13.024 g 10 cm	11.159 g 10 cm	36.778 g 10 cm
Biomass (living)		55.430 g	58.763 g	78.258 g	81.609 g	39.869 g	72.608 g
Biomass total		110.745 g	90.134 g	122.729 g	107.898 g	65.040 g	111.503 g

Table A-6. ***Picea*** **area: (O-1633205, N-6699427)**

		1	2	3	4	5	6
Groundlayer	Weight Dominant vegetation	60.905 g Bryophytes 90%	53.063 g Bryophytes 100%	86.469 g Bryophytes 100%	38.346 g Bryophytes 100%	69.394 g Bryophytes 95%	35.038 g Bryophytes 100%
Fieldlayer	Weight total Green Brown Dominant vegetation	 2.041 g 0.090 g Grasses 25%, V.myrtillus 25%					
Litter	Weight Depth	24.852 g 2 cm	7.222 g 0.5 cm	24.579 g 0.5 cm	7.624 g 0.5 cm	12.348 g 0.5 cm	48.986 g 0.5 cm
	Comp.		*Picea* needles, sticks and cones as well as some birchleaf				
Root zone	Weight Depth	17.984 g 15 cm					
Biomass (living)		81.020 g	53.063 g	86.469 g	38.346 g	69.394 g	35.038 g
Biomass total		105.872 g	60.285 g	111.048 g	45.970 g	81.742 g	84.024 g