Exercises 1- 3

1. **Litter fall vs climate change**
2. **Calculations of period mass loss, e.g. annual mass loss**
3. **Adapting simple functions to litter accumulated mass loss**

Exercise 1. Foliar litter fall

Purpose of the exercise

We will use existing data and calculate the effect of climate change on amounts of foliar litter fall. To this purpose we have collected litter fall data from a climatic gradient and listed some basic climatic factors at each stand. The data range from north of the Arctic circle to the Mediterranean.

Task; To calculate the effect of climate change on amounts of foliar litter fall

General instructions and equipment

You have a small data base in Exxel on two files (named 'Data Arctic circle to the Mediterranean' and 'Fennoscandia climate change'), with real data for foliar litter fall from pine. In addition, in a third file, called 'Discussion' you will find figures for some cases we will discuss later. Pine litter fall in this case means from different pine species viz. Scots pine, Lodgepole pine, Monterey pine, Stone pine and Maritime pine. The stands are located from the Arctic circle in Scandinavia to southernmost Spain (66.53^{o}N to 38.12^{o}N).

In the data base you have;

(i) Average values for litter fall in kg per hectare and year

(ii) the latitude of each stand given in decimal form

(iii)the annual average temperature (AVGT) for the sites

(iv)the average annual precipitation (PRECIP) for the sites

(v) the annual actual evapotranspiration (AET) for each site

Over Europe there is a large range in all the three parameters and we intend to investigate them and I would suggest the following order;

In a **first step** – check for info in the literature/data base that may be misleading

In a **second step** – investigate for variation in limiting factors over the whole range

In a **third step** – investigate for effects of a climate change scenario

So, I would like you to do the following;

Step one.

Run linear regressions of litter fall as dependent variable vs the parameters to investigate their correctness. Such runs will also give you an overview to the data. Are there any real outliers? What do you obtain?

Step two.

Next step is the investigation of variation in limiting factors. The only possible limiting factors we have in our data base are temperature and precipitation so try and use them. Before you start running regressions you may want to have a theory or an idea about the limiting factors, for example as regards the regions they may cover. A help is that the data covers three climatic zones, namely boreal, temperate and subtropical (Mediterranean). What difference in limiting factors would you expect?

Please save the following;

Printout from the run on litter fall vs latitude.

The functions and results from your runs on litter fall vs average temperature, precipitation and actual evapotranspiration.

Step 3

This data base allows us to run a climate change scenario, although there are some limitations. For the area about north of the German-Polish coastline or the

Fennoscandian region there is an estimate of an increased annual average temperature of 4^{o}C and c. 40% higher precipitation which gives an increase in AET of c. 27%. That is after a full climate change. The climatic data you have are 30-year average values that were calculated in the period 1985-1990 and they may be considered base values.

In the Exxel sheet with the data base for Fennoscandia you will find a group of data with" Situation today" and another group with "Situation after a climate change", which is a set with changed data for average temperature, annual precipitation and AET. All data here apply to sites at latitudes above 55^{o}N. Now – ASSUMING THAT NOTHING ELSE LIMITS tree growth and litter fall I want you to do the following;

Calculate litter fall 'today' by using today's data and all sites north of 55^{o}N. Take AET as parameter. You will obtain a function which you can use for calculating the effect of climate change on litter fall.

Let us focus on and investigate two places. One at a latitude of 56.4^{o}N. In the data base it is called '10:1' and is located a bit north of Copenhagen. The other point is located on the Arctic Circle and has been called '100' as identification number. It is on the top of the list.

Calculate the new litter fall and compare the increase.

Some comments to the results of the Exercise on foliar litter fall

Step one.

Comments. What may appear in databases are simply errors in numbers such as too high or negative rainfall or a too high or too low value on the AET. Never, ever trust a set of literature data or a new data base at face value. Always check it.

Step two – any limiting factors?

Comments. I would run step 2 starting with **latitude**. As you see (figure 1) there is a clear trend to increasing litter fall with sinking latitude, until a certain point, where it decreases falls, in this case somewhere below 48°N. Such a change in trend may give a hint about a change in limiting factors.

As you see, we have used AET which is a measure on evapotranspiration and thus includes both temperature and precipitation. Such a parameter may be useful as it is not always very clear whether temperature or precipitation is limiting. Although one factor (e.g. of temp and precip) generally is more limiting than the other that may be seen on a larger scale and a measure that integrates both factors may give a better fit in a regression (e.g. better R^2).

In a next step I could take **AVGT** and **PRECIP** separately and I selected **AVGT** (annual average temperature). When we have run a linear regression using all data over all climate zones we obtain a good R^2 with 0.516. We may see (Figure 2) that the litter fall increases with temperature. However, a closer look shows that there is a break in the trend at ca 10 deg annual average temperature. What could such a break be due to? We can conclude that until an annual average temperature of ca 10.5 deg there appears to be an approximately linear relationship (R^2 = 0.727;n=40)(Figure 3). This hints that temperature may be a limiting factor in a certain interval.

We may investigate what influence **PRECIP** (the annual precipitation) may have on litter fall over this region. For the whole region (Figure 4) we cannot see any trend and a linear regression gave an R^2 of 0.184 (n=45).

As regards the two limiting factors AVGT and PRECIP we may conclude that in the AVGT interval up to ca 10 degrees, temperature is limiting.

One possibility to have a good linear regression for the whole region is to use an integrated measure such as **AET** (Figure 5), and we may see that there is a clear trend in the whole interval, namely an increasing litter fall with increasing AET.

Step 3, effect of a changed climate

This data base allows us to run a climate-change scenario, although there are some limitations. For the Fennoscandian area there is an estimate of an increased annual average temperature of 4^{o}C and c. 40% higher precipitation which gives an increase in AET of c. 27%.

In this region temperature was limiting as we found (above). There are different possibilities to use the data. We can use temperature (AVGT) or we can use AET as both give a good linear relationship. I have used AET, in this case at latitudes above 55^{o}N. In a first step I calculated the 'normal' or today's relationship, which resulted in the equation below;

Litter fall = -3539.9 + 10.869AET (R^2 =0.487, n=34)

When we use today's AET values for the two places we wanted to investigate, one at the Arctic Circle (AET = 382 mm) and the other ca 80 km north of Copenhagen (AET = 519 mm) we obtain from the equation the litter fall values 612 kg/ha/yr and 1731 kg/ha/yr, respectively.

To calculate the situation after a full climate change we may simply use the same equation and the 'new' AET values for the two places we investigate. Doing that we obtain the new litter fall with 2101 kg/ha/yr and 3623 kg/ha/yr, respectively.

We may thus see that at the northern stand the needle litter fall increased from 612 to 2101 kg/ha/yr or with a factor of 3.4 and the southern one from 1731 to

3623 kg/ha/yr or with a factor of 2.1. Such a result as this depends, of course, on what other limiting factors that may influence. Such ones may be nutrients; nitrogen is added from deposition and from dinitrogen fixation. If these two processes will increase much enough to supply the needed amount of N we just do not know, as they may be influenced too of the climate change. Other nutrients are released by weathering from the mineral soil, a process which now will take place under a changed climate. Still we may regard the calculated increase as a potential one.

Exercise 2. Calculating annual litter mass loss during decomposition

The exercise is given in two steps, first we describe the principle and in a second step we apply this to a problem.

Presentation of task 1.

The data used for this exercise originate from a study on decomposition of Scots pine needle litter. The litter bags were incubated for 5 years and collected a few times a year with 20 replicates in each sampling (Table 1).

Table 1. Average accumulated mass loss and the remaining mass for consecutive samplings.

Date (yymmdd)	*Incubation time (days)*	*Accumulated mass loss (%)*	*Remaining mass (%)*
740502	0	0	100
740902	123	10.4	89.6
741103	185	17.8	82.2
750411	344	24.4	75.6
750513	376	27.3	72.7
750904	490	35.7	64.3
751029	545	43.2	56.8
760428	734	44.4	55.6
760825	846	51.2	48.8
761110	923	55.8	44.2
770601	1126	58.8	41.2
770912	1229	63	37
771027	1274	63.8	36.2
780522	1481	66.5	33.5
780831	1582	70.8	29.2
781016	1628	71.4	28.6
790514	1838	75	25
791002	1979	77.1	22.9

The task is to calculate annual mass loss rates for consecutive one-year periods. Please note – a 'year' here means, for practical reasons just circa a year and often 365 days +/- 10 days.

Comments, task 1

First we select the one-year periods, and e.g. 376 days is approximately one year. 734 days makes about 2 years, 1126 is a bit too much for 3 years, but we let it pass here and 1481 is about OK, too, as is 1838 for five years.

After 376 days there is 72.7 % left of the litter. If you prefer to use grams and milligrams there are 727 mg out of initially 1.0 gram. After 2 years there was 55.6 % or 556 mg out of 1.0 initial gram. Likewise 41.2, 33.5 and 25% or 412, 335 and 250 mg out of 1.0 initial gram for years 3, 4 and 5, respectively.

So let us calculate the mass loss in year 2, that is the period between 376 and 734 days. On day 376 there are 727 mg left and on day 734 there are 556 mg. In this one-year period 171 mg were decomposed. At the start of this period (at 376 days) there was 727 mg left. Thus 171/727 or as percent 100x171/727 which is 23.5%.

We calculate in a similar way for years 3, 4, and 5 and obtain

Yr 1 27.3
Yr 2 23.5
Yr 3 25.9
Yr 4 18.7
Yr 5 25.3

A logical question is 'to what purpose do we calculate this period mass loss or annual mass loss?' We therefore have added an exercise that will illustrate this.

Problem presentation, task 2

The data given in the table below present results of an experiment with litter decomposition rates at one Scots pine stand using needle litter with five different nutrient levels. Ih needles originate from a very nutrient-poor Scots pine forest, N0 from a Scots pine forest on relatively rich soil – although still N and P are limiting for the microorganisms. N1, N2 and N3 are denominations for litter originating from stands fertilized with 40, 80 and 120 kg N as ammonium nitrate per hectare and year. We may thus consider this as an exercise about effects of N deposition. The litter bags were incubated in parallel with all five litter types using the same design in the same stand for 4 years and litter bags sampled at the same dates. Besides litter mass loss, the litter was also analyzed for concentrations of, among other components, lignin. A condition for such an analysis is of course that lignin has been analyzed on all samples.

The task: To relate decomposition rate of Scots pine needle litter to lignin concentrations for the years 2, 3, and 4. What do you obtain?

Ih litter

Incubation time (days)	*accumulated mass loss (%)*	*Lignin ($mg\ g^{-1}$)*
0	0	267
202	11.1	n.d.
305	21.6	308
350	26.5	323
557	35	370
658	47	419
704	48.1	415
930	52.6	439
1091	59.9	442
1286	n.d.	n.d.
1448	67.5	482

N0 litter

Incubation time (days)	*accumulated mass loss (%)*	*Lignin ($mg\ g^{-1}$)*
0	0	256
202	13.8	327
305	26.2	338
350	32.7	364
557	n.d.	n.d.
658	47.4	418
704	51.2	438
930	56.3	437
1091	62	456
1286	62.2	467
1448	68.8	486

N1 litter

Incubation time (days)	*accumulated mass loss (%)*	*Lignin (mg g^{-1})*
0	0	251
202	14	310
305	26.7	340
350	31.3	367
557	n.d.	n.d.
658	47.6	431
704	49.3	437
930	53.4	456
1091	59.4	463
1286	63.2	466
1448	67.7	480

N2 litter

Incubation time (days)	*accumulated mass loss (%)*	*Lignin (mg g^{-1})*
0	0	269
202	15.5	344
305	28.5	369
350	32.2	269
557	n.d.	n.d.
658	50	442
704	51.1	453
930	53.6	453
1091	60	466
1286	64.8	467
1448	70.4	490

N3 litter

Incubation time (days)	*accumulated mass loss (%)*	*Lignin (mg g^{-1})*
0	0	268
202	18.3	353
305	30.3	388
350	36.3	401
557	n.d.	n.d.
658	50.7	452
704	53	464
930	58	469
1091	60.4	458
1286	64.9	481
1448	67.6	480

Comments to task 2

One way of determining regulating factors for litter decomposition is to use the mass loss over a certain period, e.g. one year. When we do this we may consider the remaining litter as a new substrate with a new chemical composition at the start of each such one-year period. In principle we can take any period and compare to litter mass loss, but since we want to determine the effect of a substrate-quality factor (lignin) that influences litter mass-loss rate, we want to avoid the influence of climate and we do that by selecting and comparing periods for which the climate (or weather) is constant for all five litter types. In the present example we have both the same and different periods, though.

So after some calculation you will have a new data base with 25 numbers:

Litter type	*Annual mass loss and lignin concentration*							
	yr 1		yr2		yr 3		yr 4	
	ml (%)	lign conc	ml (%)	lign conc	ml (%)	lign conc	ml (%)	lign conc
Ih	26.5	267	29.4	323	22.8	415	19.0	442
N0	32.7	256	27.4	364	22.1	438	18.0	456
N1	31.3	251	26.6	340	19.3	437	20.4	463
N2	32.2	269	27.9	385	17.3	453	26.7	466
N3	36.3	268	26.3	401	15.7	464	18.2	458

Just to demonstrate the use of annual (or period) mass loss, we suggest that you do the following. Plot the values for annual mass loss for the years 2,3, and 4 against lignin concentration. That will give you a negative relationship with n=15.

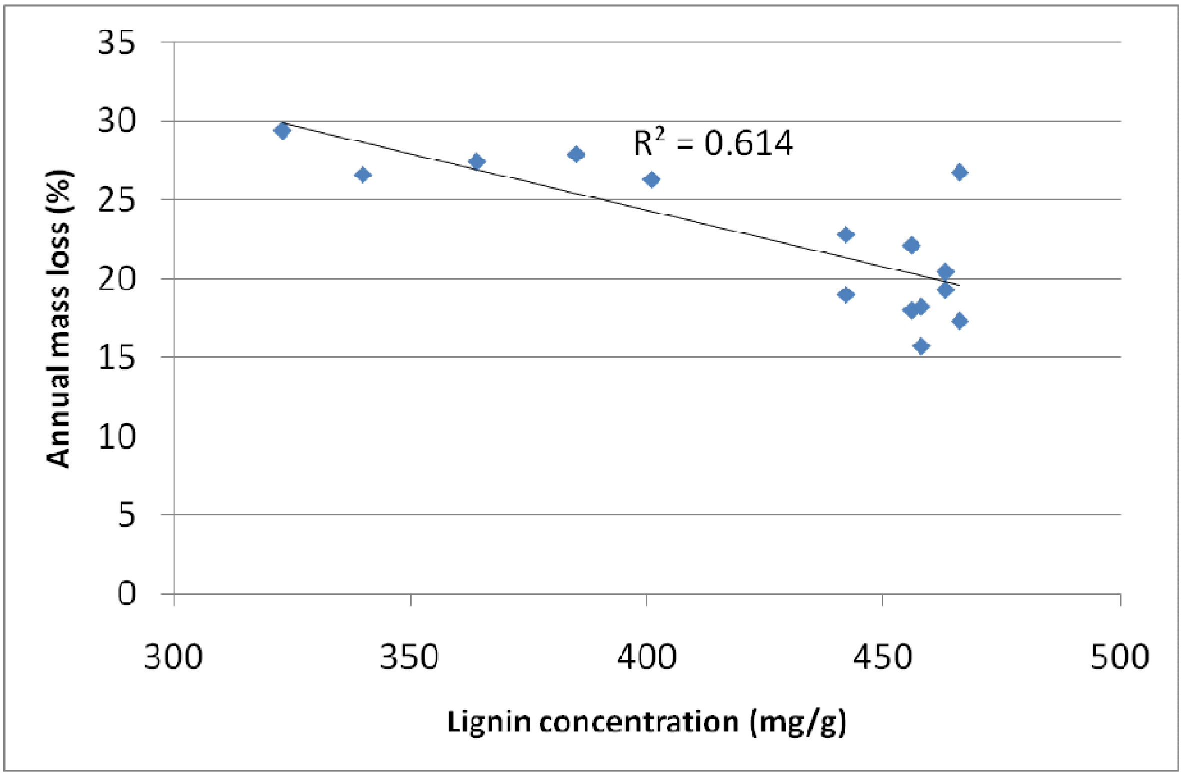

Figure 1. Linear relationship between concentration of lignin and annual mass loss.

Exercise 3. Adapting simple functions to litter accumulated mass loss

We have used real data from field studies in boreal forests and selected some different litter types that may illustrate the three main functions for decomposition 'kinetics'. These are given in the web page of Berg and Laskowski (2006). These functions should be regarded as analytical tools and do not reflect any real kinetics comparable with chemical or enzymatic kinetics.

We present this exercise as two main tasks, with subtasks Nos 1-3 on sheets 1-3 on one spreadsheet and subtasks 4-6 on another with one set of data per sheet.

Below follow comments to each task.

Task 1

The purpose of this task is; (i) to make you familiar with the use of the functions and (ii) an attempt to synthesize knowledge of litter chemical composition and the shape of the mass loss graph.

So, please compare how well the three functions fit to measured mass-loss data for;

Lodgepole pine (sheet 1). Data from Berg and Lundmark (1985)
Silver birch (sheet 2). Data from Berg and Ekbohm (1991) and Berg et al. (1991)
Grey alder (sheet 3). Data from Berg and Ekbohm (1991) and Berg et al. (1991)

Can you see some reasons to why the patterns for accumulated mass loss are so different? Please think about possible reasons just as an exercise. You have all chemical data given in the spreadsheets and may use them. Below, under Comments you will find our interpretations. Please note that the comments we make are so far mainly speculations and at least not yet shown to be the causal relationships. Let us say that the comments are rather intended to stimulate your thinking.

Task 2

The purpose of this task is the same as for task 1, namely (i) to make you familiar with the use of the functions and (ii) an attempt to synthesize knowledge of litter chemical composition and the shape of the mass loss graph as well as the fit of a function.

So, please compare how well the three functions fit to measured mass loss data for;

Norway spruce (sheet 1). Data from Berg and Tamm (1991)
Scots pine (sheet 2). This sheet has four sets of data, all of Scots pine needle litter but with somewhat different chemical properties. Data from Berg and Staaf (1980) and Berg et al. (1991)

Can you see any possible explanation to the pattern for Norway spruce needle litter?

What can you distinguish when you compare the three functions for the different sets of Scots pine data. Can you imagine an explanation or see any pattern with litter chemical composition within the species?

Like for task 1 - please note that the comments we make are so far mainly speculations and at least not yet shown to be the causal relationships.

Comments, task 1.

Lodgepole pine needle litter

For lodgepole pine litter you obtained an R^2_{adj} of 97.4 for a single exponential, 98.1 for a double exponential and 97.4 for an asymptotic function. The asymptote was well above 100% which means that in spite of the high R^2 value the function does not fit. The double exponential had its compartments wrong. One was negative and one above 100% so we discard also that one. Remains the single exponential which is highly significant.

Further comments.

We may apply a simplified view on the pattern and consider an early and a late stage. A high rate in an early stage and a low rate in a late stage would intuitively give a picture of a litter that fits to a double exponential and an asymptotic function. On the other hand, a low initial rate (in an early phase) and a higher rate in the later phase would support that the litter would decompose according to a single exponential. We can try and use this reasoning to explain the patterns.

The lodgepole pine needles have a relatively low concentration of water solubles, which may be relatively easy to degrade and otherwise could have given a high initial rate. The relatively low initial concentrations of the major nutrients (N, P; compare to those of e.g. grey alder and silver birch leaves) also would give a low initial rate. So, some factors support a low rate in the early stage. For the late stage, factors that support a high lignin degradation could be expected to support a high rate. For example a low initial N concentration would mean a relatively low suppressing effect of N on lignin degradation, and the relatively high values for Mn concentration may facilitate lignin degradation.

Grey alder leaf litter

For grey alder leaves you obtained a low R^2_{adj} for the single exponential (R^2_{adj} =0.026 or 2.6%). For the double exponential R^2_{adj} was 0.949 (or 94.9%) and for the asymptotic function 0.975 (or 97.5%) with an asymptote at 50.6% and we may conclude that the two latter functions fit much better. Still with so similar

R^2_{adj} values for the double exponential and the asymptotic function we cannot really say that one fits better than the other.

Further comments.
We may apply a simplified view on the pattern and consider an early and a late stage. A high rate in an early stage and a low rate in a late stage would intuitively give a picture of a litter that fits to a double exponential and an asymptotic function. On the other hand, a low initial rate (in an early phase) and a higher rate in the later phase would support that the litter would decompose according to a single exponential. We can try and use this reasoning to explain the patterns also in this case.

We may see that the grey alder leaves had an initially very high concentration of water solubles (254 mg/g) that had decreased to 48 mg/g at 204 days. This supports of course a high initial mass loss and such a high mass loss is supported by high concentrations of N, P and S. So these factors together would support a high initial decomposition rate (in the early phase).

For a late stage a low degradation rate of lignin (and of litter) may be expected as the high N concentration may hamper lignin degradation rate (to a higher extent than for lodgepole pine) and the Mn concentration is low and may be expected to support lignin degradation to a lower extent, if at all. Please note – we know too little to set absolute limits for effects of N and Mn on lignin degradation and therefore we compare to degradation of lodgepole pine needles with low N and high Mn concentrations.

Silver birch leaf litter
Finally for silver birch the R^2_{adj} value for the single exponential is low (51.1%), for the double exponential 98.0 and both W1 and W2 have a reasonable size. For the asymptotic function the R^2_{adj} value is 97.3 and the limit value 54.3%. We may conclude that both functions fit very well.

Further comments.
We may apply a simplified view on the pattern and consider an early and a late stage. A high rate in an early stage and a low rate in a late stage would intuitively give a picture of a litter that fits to a double exponential and an

asymptotic function. On the other hand, a low initial rate (in an early phase) and a higher rate in the later phase would support that the litter would decompose according to a single exponential. Again, we can try and use this reasoning to explain the patterns.

We may see that the silver birch leaves had an initially very high concentration of water solubles (241 mg/g) that had decreased to 53 mg/g at the sampling after 204 days. This supports of course a high initial mass loss and such a high mass loss is supported by high concentrations of N, P and S. So these factors together would support a high initial decomposition rate (in the early phase).

For a late stage a low degradation rate of lignin (and of litter) may be expected as the high N concentration may hamper lignin degradation rate (to a higher extent than for lodgepole pine). The Mn concentration is low and may be expected to support lignin degradation to a lower extent. Please note – we know too little to set absolute limits for effects of N and Mn on lignin degradation and therefore we compare to degradation of lodgepole pine needles also in this case.

Comments, Task 2.

Norway spruce needle litter

For Norway spruce needle litter you obtained an R^2_{adj} of 90.84% for a single exponential, 97.5% for a double exponential and 95.9 for an asymptotic function. The asymptote was 46.6% mass loss and k_{init}=31.54. The double exponential had the 'fast compartment' at 8.59% and the slow one at 91.4% with k_1 = -12.46 and k_2 = -0.159.

Our general conclusion is that both the double exponential and the asymptotic function appear to fit better than the single exponential. That conclusion is based on the values for R^2_{adj}.

Scots pine needle litter of different chemical composition

We have indicated the different N concentrations in the three tables below and use them in the table below to separate the three sets.

Single exponential

	N	R^2_{adj}	k
Low N	4.4 mg/g	97.55	0.3160
Low medium N	7.0 mg/g	97.23	0.3313
High medium N	8.1 mg/g	94.86	0.3457
High N	15.1 mg/g	92.42	0.3364

Double exponential

	N	R^2_{adj}	W1	k1	W2	k2
Low N	4.4 mg/g	98.81	73.4	0.5455	27.8	0.0267
Low medium N	7.0 mg/g	98.41	49.9	0.7419	51.21	0.1443
High medium N	8.1 mg/g	99.16	71.6	0.6848	29.3	0.0070
High N	15.1 mg/g	99.19	36.1	1.2996	64.2	0.1627

Asymptotic

	N	R^2_{adj}	Asymptote	K_{init}
Low N	4.4 mg/g	99.06	77.36	38.53
Low medium	7.0 mg/g	98.78	77.98	40.61
High medium N	8.1 mg/g	99.35	72.12	47.41
High N	15.1 mg/g	99.19	68.08	49.15

Comments

One intention behind this exercise was to identify any trend in the material. A trend may be distinguishable as all litter belonged to the same species and all litter was incubated in the same stand, thus several influencing factors were set equal. All regressions are highly significant and we may investigate k-values, W-values (compartment) or asymptote levels within each model to find trends. Four values for a trend is not much material to work on, still we have the advantage of having one species, although the range in chemical composition within one species is limited. The initial concentrations of water solubles, and lignin were similar and the difference in N and major nutrients. We may conclude that there was no clear trend in the material, for the single and double exponentials, but there may be one for the asymptotic one with decreasing limit values with increasing N levels and increasing K_{init} with increasing N concentrations.

Literature references

Berg, B. and Ekbohm, G. 1991. Litter mass-loss rates and decomposition patterns in some needle and leaf litter types. Long-term decomposition in a Scots pine forest VII. Canadian Journal of Botany 69:1449-1456.

Berg, B. and Lundmark, J.-E. 1985. Decomposition of needle and root litter in lodgepole pine and Scots pine monocultural systems. Dept. of Forest Ecology and Forest Soils. Swedish University of Agricultural Sciences, Uppsala. Research notes No 53,76 pp.

Berg, B., Booltink, H.G.W, Breymeyer, A., Ewertsson, A., Gallardo,A., Holm, B., Johansson, M.-B., Koivuoja, S., Meentemeyer, V., Nyman, P., Olofsson, J., Pettersson, A.-S., Staaf, H., Staaf, I. and Uba, L. 1991. Data on needle litter decomposition and soil climate as well as site characteristics for some coniferous forest sites. 2nd ed. Section 2. Data on needle litter decomposition. Swedish University of Agricultural Sciences. Department of Ecology and Environmental Research. Report No 42.

Berg,B. and Tamm,C.O. 1991. Decomposition and nutrient dynamics of Norway spruce needle litter in a long-term optimum nutrition experiment. I. Organic matter decomposition. Swedish University of Agricultural Sciences. Department of Ecology and Environmental Sciences, Report No 39.

Berg, B. and Staaf, H. 1980. Decomposition rate and chemical changes of Scots pine needle litter. II. Influence of chemical composition. In: Persson, T. (Ed.) Structure and Function of Northern Coniferous Forests - An Ecosystem Study. Ecol. Bull. (Stockholm) 32: 373-390.