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Variation in Mass-Loss Rate of Foliar Litter in Relation to Climate and Litter Quality in Eurasian Forests: Differences among Functional Groups of Litter

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With a data set of litter decomposition collected by means of literature survey, our objectives are 1) to determine the differences in the variation in the first-year mass loss (%) of leaf litter with regard to climate and litter quality among different functional groups of tree species in Eurasian forests, and 2) to determine the difference in effect of mean annual temperature (°C), annual precipitation (dm), as well as concentration of nitrogen (%), and lignin (%) on first-year mass loss over a wide range in climate and litter quality. The main results are as follows. 1) The significant differences between litter types in the relationships between first-year mass loss and climatic factors plus litter quality revealed clearly different decomposition patterns over the continent. Thus, differences were found between coniferous and broadleaf litter, between deciduous broadleaf and evergreen broadleaf as well as between genera and even within a genus, viz. between deciduous and evergreen *Quercus*. 2) With a change in a relative unit of climate and litter quality variables, there were clear differences in effects of mean annual temperature, annual precipitation, and nitrogen on first-year mass loss for different functional groups of trees. 3) We identified some broadleaf litter species that decomposed to 100% in one year and thus did not contribute to carbon sequestration in a humus layer. Thus, the variation in pattern of foliar litter decomposition with climate and litter quality across functional groups in Eurasian forests showed different decomposition strategies for litter of different groups and genera.

Keywords climate, Eurasian forests, leaf litter, mass-loss, litter quality, carbon sequestration
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1 Introduction

Litter decomposition is an essential process in ecosystems, concerning the emission and storage of carbon (C), nutrient release, as well as formation of humic substances in the soil (Swift et al. 1979, Pastor and Post 1986, Coûteaux et al. 1995, Berg 2000, Parton et al. 2007). As seen in some studies, global forest litter production has been estimated to be as high as 29×10^{15} g yr^{-1} (Lonsdale 1988). Foliar litter occupies a major fraction of the litter in forest ecosystems (Matthews 1997) and may be totally decomposed within a year in subtropical and tropical areas (Meentemeyer 1984). It is thus of importance to investigate the pattern of forest litter decomposition and influencing factors for a deeper understanding of global carbon dynamics.

The decay rate of newly shed litter is controlled by several major factors, which may be dependent on the scales across which an investigation is conducted. Such factors may be litter quality (e.g. Melillo and Aber 1982), site conditions including microbial community (e.g. Vitousek et al. 1994, Liu et al. 2001) or plant type (e.g. Cornelisen 1996, Hobbie 1996). At a regional to global scale the process can be related mainly to climate and litter quality (Meentemeyer 1978, Aerts 1997, Moorhead et al. 1999, Liski et al. 2003, Zhang et al. 2008).

In previous studies, the pattern of leaf litter mass loss was demonstrated by combining litter species (e.g. Meentemeyer 1984) or by using just one genus (e.g. Liski et al. 2003), but few comparisons have been made about differences in mass-loss pattern among groups of foliar litter species along a broad climate gradient. We have as a working hypothesis that there are differences between functional groups in-mass loss pattern in relation to climatic and substrate-quality factors.

The objectives of this study were, (i) to determine the overall patterns of first-year mass loss (FML) of foliar litter versus climatic and litter-quality variables in Eurasian forests; (ii) to determine the difference in the relationships of FML with climate and litter quality among different genera and functional groups; (iii) to determine relative effects of mean annual temperature (MAT, Temperature, °C), annual precipitation (APT, Precipitation, dm) as well as of nitrogen (N, %) and lignin on FML at a continental scale.

The Eurasian continent comprises a variety of climatic conditions, and a broad diversity of tree species, which provides a way to demonstrate the relationships between litter mass loss, climatic factors and litter quality at a continental scale. Eurasian forests currently cover more than 1.6×10^9 ha, making up 41% of the total global forested area (FAO 2001), and CO_2 emission and soil storage of C from litter decomposition is thus an important component in the global carbon fluxes.

2 Methods

2.1 Data Collection

The data used in this study were collected by survey of literature, and a data set of 295 FML values of foliar litter was compiled including data on concentration of N and lignin (Appendix A). Not all litter-quality variables were always available. We thus had 124 sets with values for concentrations of lignin and 200 sets with that of N. When the original paper did not provide climate data, Temperature (here refer to mean annual temperature, MAT, the same after, °C) and Precipitation (here refer to annual precipitation, APT, the same after, dm) values were taken from Müller's (1982) climate collection on the basis of the geographical co-ordinates. For stands with weather stations at greater distance than 1 degree in latitude or longitude, climatic data were interpolated among surrounding weather stations.

2.2 Data and Data Processing

The first-year mass loss (FML) values ranged from 10.0 to 100% with N concentration ranging from 0.1 to 4.8% and those of lignin from 4 to 50%. Temperature ranged from –1.7 to 30.2 °C and Precipitation from 4.43 to 30.4 dm. The average value for N was 0.49% for coniferous and 1.15% for broadleaf litter. With standard errors (SE) of 0.02 and 0.06, respectively, they were significantly different. For lignin concentration, the average value was 29.1% for coniferous and 17.9% for broadleaf litter, which were significantly different ($p < 0.001$) (Table 1). The

Table 1. Average concentrations of nitrogen and lignin for the litter groups coniferous, broadleaf, evergreen broadleaf (Evergr Br) and deciduous broadleaf (Dec Br) as well as significant differences.

Litter types	Nitrogen (%)	SE	n	Lignin (%)	SE	n
Coniferous	0.49 a	0.02	78	29.14 a	0.65	62
Broadleaf	1.15 b	0.06	122	17.89 b	1.32	62
Dec Br	1.10 b	0.12	51	14.62 b	1.91	21
Evergr Br	1.19 b	0.07	71	19.57 b	1.70	41

Within each column different letters indicate highly significant differences (t-test, $p<0.001$)

distribution of data within each of the variables is seen in Fig. 1.

We subdivided the data in a first step into the categories broadleaf and coniferous litter. Further we divided 'broadleaf' into the subgroups 'deciduous broadleaf' and 'evergreen broadleaf'. At genus level, we analyzed the separate genera *Pinus* (pine), *Picea* (spruce), *Quercus* (oak) and subdivided *Quercus* into deciduous and evergreen.

With natural-log transformed FML, we calculated simple and multiple regressions between FML and Temperature and Precipitation. We used linear and exponential regressions to describe the effects of N and lignin concentrations on FML. We used the software SigmaStat (SPSS 1997).

To determine relative influences on FML, data for Temperature, Precipitation, and N were transformed using the program Standardize Transform (SPSS 1997). The standardized variables are dimensionless with a mean of zero and a standard deviation of 1.0. Thus, in a multiple regression equation, the values of the coefficients indicate their contributions to the variation in FML. In order to show the differences in the effect of Temperature, Precipitation and N on FML in an equation, t-test was applied to test if a significant difference exits between the coefficients of these independent variables. A similar test was also made on the effect of Temperature (or Precipitation, and N) on FML between the equations representing different litter groups.

The fit of regression equations was assessed with the coefficient of determination (R^2). The adjusted coefficient of determination (R^2_{adj}) allows us to compare the goodness of model fit by taking into account the number of samples used (Ekbohm and Rydin 1990). We used t-test to determine the difference between the coefficients of independent variables within a multiple regression equation and between the coefficients of independent variables in pairs of equations.

3 Results

3.1 Mass Loss of Different Foliar Litter Types in Relation to Climatic Factors

For all data combined (broadleaf plus coniferous litter), R^2_{adj} was 0.407 with Temperature and Precipitation as independent variables (Table 2). For broadleaf litter, R^2_{adj} became 0.307 and for coniferous $R^2_{adj}$was 0.124. Broadleaf and coniferous litter as separate groups both had significant linear relationships ($p<0.001$) between FML, Temperature and Precipitation as independent variables in single or multiple regressions (Table 2, Fig. 1).

There was a higher variation among FML values for broadleaf foliar litter samples than for coniferous (Fig. 1). Broadleaf foliar litter generally had higher FML under the same climatic conditions as compared with coniferous litter. Thus, maximum FML reached 100% for broadleaf litter at a Temperature of 15 °C and above and at a Precipitation of 15 dm, but only c. 60% for coniferous litter at the same Temperature and Precipitation (Fig. 1).

Similar to broadleaf and coniferous litter, the groups 'deciduous broadleaf' and 'evergreen broadleaf' litter were highly significant ($p<0.001$) for the relationships between FML and the climatic factors (Table 2, Fig. 2). Evergreen broadleaf litter had a clearly better relationship to

Table 2. Linear regressions of the first-year mass loss of foliar litter (FML) against the climatic factors mean annual temperature (MAT, °C) and annual precipitation (APT, dm) for broadleaf and coniferous litter types combined (All litter), as well as coniferous, broadleaf, deciduous broadleaf (Dec. Br) and evergreen broadleaf (Evergr. Br) litter as separate groups. Standard error (SE) is given.

Litter groups	Intercept			MAT			APT			n	R^2_{adj}	p
	C	SE	p	A	SE	p	B	SE	p			
ln(FML) = C + A × MAT												
All litter	3.259	0.047	<0.001	0.035	0.003	<0.001				295	0.293	<0.001
Coniferous	3.207	0.048	<0.001	0.024	0.006	<0.001				116	0.119	<0.001
Broadleaf	3.469	0.085	<0.001	0.027	0.005	<0.001				179	0.150	<0.001
Dec Br	3.582	0.083	<0.001	0.020	0.006	<0.001				94	0.108	<0.001
Evergr Br	3.009	0.223	<0.001	0.048	0.011	<0.001				85	0.191	<0.001
ln(FML) = C + B × APT												
All litter	3.153	0.049	<0.001				0.045	0.003	<0.001	295	0.362	<0.001
Coniferous	3.162	0.066	<0.001				0.025	0.008	<0.001	116	0.079	<0.001
Broadleaf	3.337	0.075	<0.001				0.039	0.005	<0.001	179	0.287	<0.001
Dec Br	3.561	0.087	<0.001				0.021	0.006	<0.001	94	0.112	<0.001
Evergr Br	2.937	0.130	<0.001				0.061	0.007	<0.001	85	0.476	<0.001
ln(FML) = C + A × MAT + B × APT												
All litter	3.088	0.049	<0.001	0.018	0.004	<0.001	0.032	0.004	<0.001	295	0.407	<0.001
Coniferous	3.152	0.065	<0.001	0.019	0.007	<0.010	0.012	0.009	=0.212	116	0.124	<0.001
Broadleaf	3.233	0.086	<0.001	0.012	0.005	0.015	0.033	0.005	<0.001	179	0.307	<0.001
Dec Br	3.474	0.094	<0.001	0.014	0.006	0.031	0.015	0.007	=0.025	94	0.147	<0.001
Evergr Br	2.518	0.182	<0.001	0.027	0.009	0.003	0.054	0.007	<0.001	85	0.526	<0.001

Temperature and Precipitation ($R^2_{adj} = 0.526$) than deciduous broadleaf with $R^2_{adj} = 0.147$ (Table 2). However, under the same climatic conditions, there was almost no difference in FML between litter of evergreen broadleaf and deciduous broadleaf although we found more data for evergreen at warmer and wetter sites (Fig. 2).

For separate genera we investigated the trends in FML in relation to Temperature and Precipitation with *Pinus* (n = 87), *Picea* (n = 18) and *Quercus* (n = 54). The latter group was subdivided into 'deciduous *Quercus*' (n = 20) and 'evergreen *Quercus*' (n = 34).

There was a positive relationship between FML and Temperature for *Pinus* ($p < 0.001$) but not with any of the other genera (Table 3, cf Fig. 3). For Precipitation there were highly significant relationships for *Picea*, *Quercus*, and evergreen *Quercus* (Fig. 3) with p = 0.001 (Table 3). For *Pinus* the p value approached significance ($p < 0.100$) but for deciduous *Quercus*, there was no significance to Precipitation (Table 3).

We found a clear variation among genera as regards the significance of the relationship between FML and the combined Temperature and Precipitation. Thus, for *Pinus* the R^2_{adj} was 0.109 (p = 0.003) and for *Picea* R^2_{adj} was 0.273 (p = 0.036). The model for combined *Quercus* was better with $R^2_{adj} = 0.352$ ($p < 0.001$). The model for the subgroup evergreen *Quercus* gave a R^2_{adj} of 0.635 ($p < 0.001$), whereas that for deciduous *Quercus* was not significant (Table 3).

3.2 Mass Loss of Different Foliar Litter Groups and Genera in Relation to Litter Quality

For coniferous and broadleaf litter, both separately and combined, the relationships between FML and N concentration were highly significant in both linear and exponential models ($p < 0.001$), but the fits were better in the latter with $R^2_{adj} = 0.408$ for all litter, 0.173 for coniferous and 0.210 for

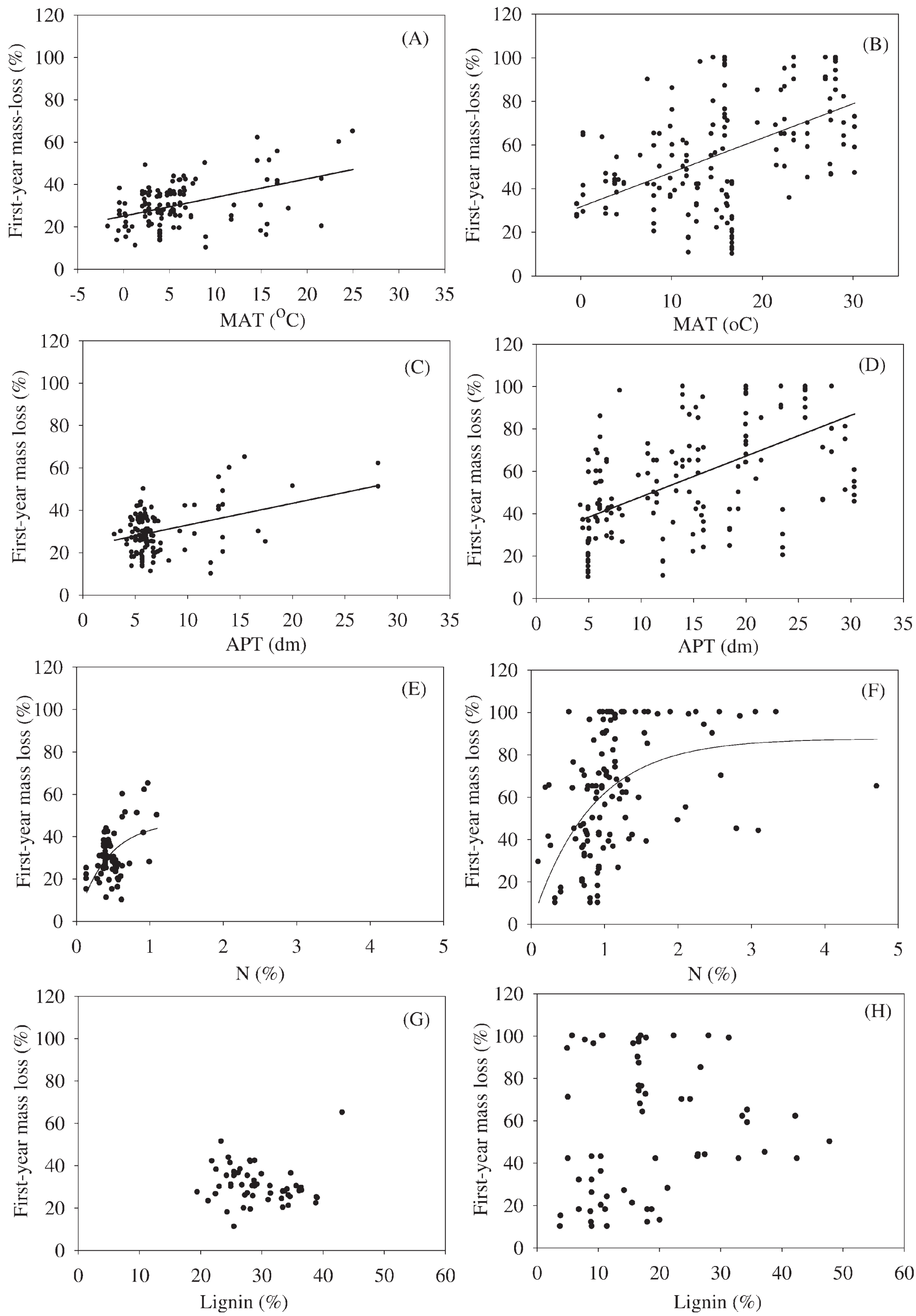

Fig. 1. Variation in first-year mass-loss in relation to mean annual temperature (MAT, °C), annual precipitation (APT, dm), initial nitrogen concentration (N,%) and initial lignin concentration (%) for coniferous (A, C, E, G) and broadleaf (B, D, F, H) foliar litter in Eurasian forests.

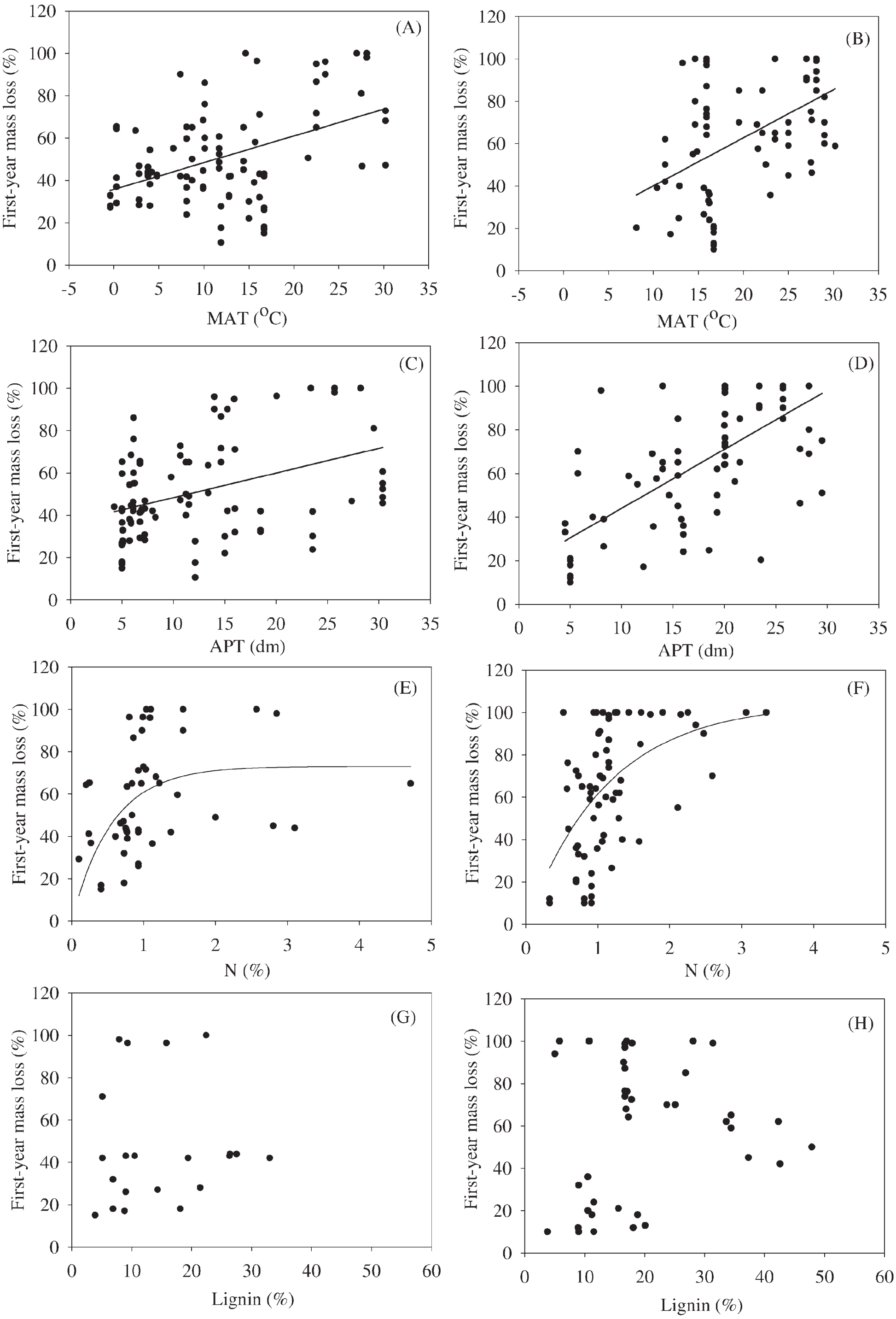

Fig. 2. Variation in first-year mass loss in relation to mean annual temperature (MAT, °C), annual precipitation (APT, dm), initial nitrogen concentration (N, %) and initial lignin concentration (%) for deciduous broadleaf (A, C, E, G), and evergreen broadleaf (B, D, F, H) foliar litter in Eurasian forests.

Table 3. Linear regressions of first-year mass loss of foliar litter ln(FML,%) against mean annual temperature (MAT, °C), annual precipitation (APT, dm) for the genera *Pinus*, *Picea* and *Quercus* as well as for the subgroups evergreen *Quercus* (Evergr Qu) and deciduous *Quercus* (Dec Qu). Standard error (SE) is given.

Litter genera	Intercept			MAT			APT			n	R^2_{adj}	p
	C	SE	p	A	SE	p	B	SE	p			
ln(FML) = C + A × MAT												
Pinus	3.208	0.056	<0.001	0.026	0.008	<0.001				87	0.116	<0.001
Picea	3.291	0.130	<0.001	–0.006	0.026	=0.819				18	0.000	=0.819
Quercus	3.425	0.244	<0.001	0.015	0.016	=0.375				54	0.000	=0.375
Evergr Qu	2.944	0.595	<0.001	0.044	0.036	=0.225				34	0.016	=0.225
Dec Qu	3.660	0.174	<0.001	–0.008	0.015	=0.600				20	0.000	=0.600
ln (FML) = C + B × APT												
Pinus	3.176	0.112	<0.001				0.027	0.016	<0.100	87	0.020	=0.100
Picea	2.919	0.126	<0.001				0.055	0.019	<0.010	18	0.305	=0.001
Quercus	2.911	0.146	<0.001				0.055	0.010	<0.001	54	0.361	<0.001
Evergr Qu	2.584	0.196	<0.001				0.074	0.012	<0.001	34	0.525	<0.001
Dec Qu	3.536	0.182	<0.001				0.004	0.016	=0.806	20	0.000	=0.806
ln(FML) = C + A × MAT + B × APT												
Pinus	3.258	0.111	<0.001	0.029	0.009	=0.003	–0.010	0.019	=0.600	87	0.109	=0.003
Picea	2.965	0.156	<0.001	–0.012	0.022	=0.602	0.056	0.019	=0.011	18	0.273	=0.036
Quercus	2.815	0.226	<0.001	0.007	0.013	=0.582	0.055	0.010	<0.001	54	0.352	<0.001
Evergr Qu	1.325	0.422	=0.004	0.072	0.022	=0.003	0.080	0.011	<0.001	34	0.635	<0.001
Dec Qu	3.618	0.241	<0.001	–0.008	0.016	=0.604	0.004	0.016	=0.796	20	0.000	=0.846

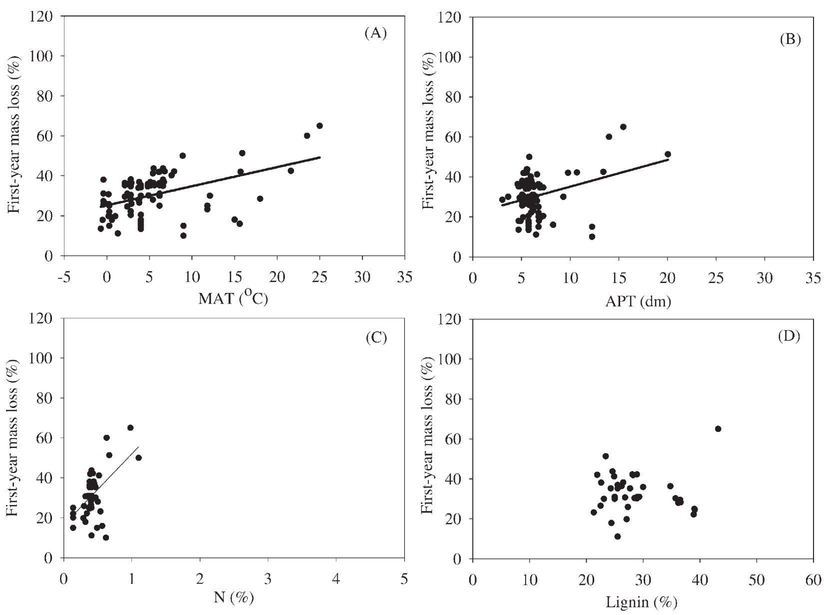

Fig. 3. Variation in first-year mass loss in relation to mean annual temperature (MAT, °C), (A), annual precipitation (APT, dm), (B), initial nitrogen concentration (N, %) (C) and initial lignin concentration (%) (D) for *Pinus* needle litter in Eurasian forests.

broadleaf litter in comparison with the linear model (R^2_{adj}=0.265 for all litter, 0.154 for coniferous and 0.131 for broadleaf litter) (Fig. 1, Tables 4 and 5).

For evergreen broadleaf litter, FML varied significantly with N in linear (R^2_{adj}=0.187) and exponential models (R^2_{adj}=0.261), both at $p<0.001$, with a better fit for the latter (Tables 4 and 5). For deciduous broadleaf litter both models were significant, but the exponential model gives a better fit (Tables 4 and 5).

For the genus *Pinus* there was a positive relationship ($p<0.001$) between FML and N as a single factor and for evergreen *Quercus* with $p<0.05$ in both a linear (Table 4) and an exponential model (Table 5). For the genera *Picea* and deciduous *Quercus* there was no significance for N as a single factor.

Lignin concentration for coniferous litter ranged from c. 20 to 40%, and for broadleaf litter from c. 4 to 50% (Fig. 1). For all litter combined as well as for coniferous and broadleaf separately, lignin was not significant as a single substrate-quality factor

Table 4. Linear regressions of the first-year mass-loss of leaf litter (ln (FML)) against initial concentration of N (%) for the main litter groups broadleaf and coniferous litter combined (All litter), coniferous, broadleaf, deciduous broadleaf (Dec Br), evergreen broadleaf (Evergr Br), as well as for the genera *Pinus*, *Picea*, *Quercus*, deciduous *Quercus* (Dec Qu) and evergreen *Quercus* (Evergr Qu). The equation used is ln(FML) = C + A × N. Standard error (SE) is given.

Litter types	Intercept			Nitrogen			n	R^2_{adj}	p
	C	SE	p	A	SE	p			
All litter	3.310	0.062	<0.001	0.480	0.056	<0.001	200	0.265	<0.001
Coniferous	3.014	0.103	<0.001	0.761	0.196	<0.001	78	0.154	<0.001
Broadleaf	3.591	0.099	<0.001	0.323	0.074	<0.001	122	0.131	<0.001
Dec Br	3.721	0.111	<0.001	0.188	0.082	=0.026	51	0.079	=0.026
Evergr Br	3.381	0.164	<0.001	0.513	0.124	<0.001	71	0.187	<0.001
Pinus	2.986	0.121	<0.001	0.939	0.257	<0.001	56	0.184	<0.001
Picea	3.192	0.242	<0.001	0.127	0.422	=0.767	18	0.000	=0.767
Quercus	2.907	0.398	<0.001	0.846	0.409	=0.045	41	0.076	=0.045
Dec Qu	3.583	0.298	<0.001	0.134	0.330	=0.694	11	0.000	=0.694
Evergr Qu	2.280	0.612	<0.001	1.464	0.614	=0.024	30	0.139	=0.024

Table 5. Exponential regressions of the first-year mass loss of foliar litter (FML) against initial litter nitrogen (N) concentration (%) as litter-quality factor for broadleaf and coniferous litter combined (All litter), as well as for the separate groups of coniferous, broadleaf, deciduous broadleaf (Dec Br), evergreen broadleaf (Evergr Br), the genera *Pinus*, *Quercus*, and *Quercus* subdivided into deciduous *Quercus* (Dec Qu) and evergreen *Quercus* (Evergr Qu). The equation used was FML = A × (1 – exp(–B × N)).

Litter types [a)]	Constant			Nitrogen			n	R^2_{adj}	p
	A	SE	p	B	SE	p			
All litter	92.004	7.347	<0.001	1.023	0.152	<0.001	200	0.408	<0.001
Coniferous	47.121	6.536	<0.001	2.420	0.672	<0.001	78	0.173	<0.001
Broadleaf	87.583	8.387	<0.001	1.223	0.252	<0.001	122	0.210	<0.001
Dec Br	73.032	8.907	<0.001	1.785	0.590	=0.004	51	0.121	=0.026
Evergr Br	104.464	16.581	<0.001	0.888	0.262	<0.001	71	0.261	<0.001
Pinus	57.710	10.664	<0.001	1.943	0.601	=0.002	56	0.289	<0.001
Quercus	104.979	103.002	=0.314	0.669	0.989	=0.503	41	0.076	=0.045
Dec Qu	43.398	4.165	<0.001	11.311	9.618	=0.270	11	0.004	=0.334
Evergr Qu	4.811	0.828	<0.001	1.558	0.639	=0.021	30	0.175	=0.013

[a)] For *Picea* the coefficients were not listed here because no model matched the data.

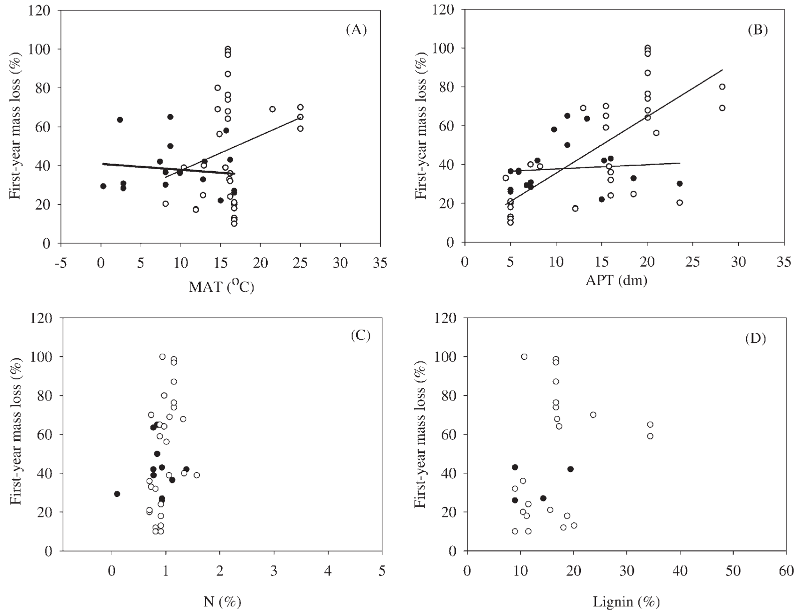

Fig. 4. Variation in first-year mass loss in relation to mean annual temperature (MAT, °C), (A), annual precipitation (APT, dm), (B), initial nitrogen concentration (N, %) (C) and initial lignin concentration (%) (D) for deciduous (solid circles) and evergreen (open circles) *Quercus* foliar litter in Eurasian forests.

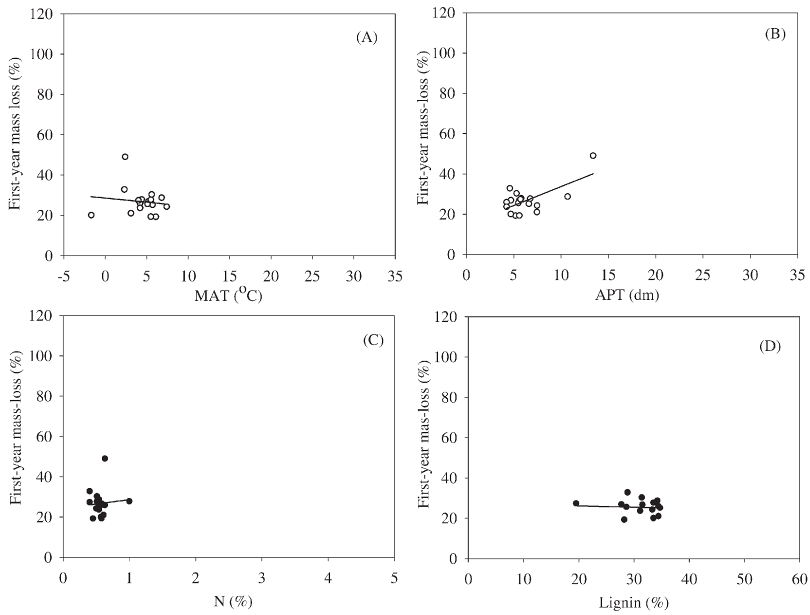

Fig. 5. Variation in mass loss in relation to MAT (°C) (A), APT (dm) (B), N (%) (C) and lignin (%) (D) for *Picea* foliar litter in Eurasian forests.

and there was no trend indicating that FML was influenced by initial lignin concentration (Figs. 1 and 2). This was also seen for deciduous and evergreen broadleaf litter. Neither for the separate genera was lignin significant as a single factor and there was no clear trend that FML was influenced by lignin concentration (Figs. 3 thru 5).

3.3 Combined Effects of Climatic and Litter-Quality Variables on First-Year Mass Loss

The multiple linear regression models of FML against Temperature, Precipitation, and N were highly significant ($p<0.001$) for the main groups, namely all litter types combined, broadleaf, coniferous, evergreen broadleaf, and deciduous broadleaf ($R^2_{adj}=0.702$ to 0.204) with $p<0.001$. For most genera we found highly significant models with $R^2_{adj}=0.223$ for *Pinus*, 0.626 for *Quercus* and 0.749 for evergreen *Quercus*. Deciduous *Quercus* gave a significant relationship ($p=0.038$; $R^2_{adj}=0.540$) whereas the litter of *Picea* did not ($p=0.093$ and $R^2_{adj}=0.221$; Table 6). For *Quercus* evergreen the R^2_{adj} even reached 0.749 explaining about 75% of the mass loss in the first year and for broadleaf evergreen 70%.

In these models, describing the combined effects of climatic factors and N, Temperature had a negative effect on FML for the groups 'broadleaf litter', '*Quercus*' and 'deciduous *Quercus*', Precipitation had a negative effect for *Pinus*, and both Temperature and N had a negative effect for *Picea* (Table 6). In none of these cases was the effect significant.

3.4 Relative effects of Annual Average Temperature, Annual Precipitation, and N on First-Year Mass Loss

By using standardized climatic and litter-quality factors and FML we found (Table 7) that the effects of Temperature, Precipitation, and N on FML in relative units were different among the groups of litter types and among genera.

For all litter combined ('All litter'), the effect of Precipitation was significantly larger ($p<0.001$) than those of Temperature and N (Table 7). In fact,

Table 6. Linear regressions of first-year mass loss of leaf litter (ln(FML)) against mean annual temperature (MAT, °C), annual precipitation (APT, dm), and initial litter nitrogen (N,%) concentration for broadleaf and coniferous litter combined (All litter), the separate groups coniferous and broadleaf, as well as deciduous broadleaf (Dec Br) and evergreen broadleaf (Evergr Br) and the genera *Pinus*, *Picea*, and *Quercus*, the latter also subdivided into deciduous *Quercus* (Dec Qu) and evergreen *Quercus* (Evergr Qu). The function used was ln (FML) = D + A × MAT + B × APT + C × N. Standard error (SE) is also given

Litter groups	Intercept			MAT			APT			N			n	R^2_{adj}	p
	D	SE	p	A	SE	p	B	SE	p	C	SE	p			
All litter	2.948	0.056	<0.001	0.005	0.004	=0.277	0.050	0.005	<0.001	0.167	0.052	=0.002	200	0.578	<0.001
Coniferous	3.042	0.105	<0.001	0.022	0.011	=0.043	0.005	0.011	=0.626	0.372	0.243	=0.129	78	0.204	<0.001
Broadleaf	3.026	0.100	<0.001	–0.002	0.005	=0.671	0.058	0.006	<0.001	0.129	0.056	=0.024	122	0.563	<0.001
Dec Br	3.286	0.116	<0.001	–0.006	0.007	=0.402	0.056	0.009	<0.001	0.077	0.064	=0.237	51	0.491	<0.001
Evergr Br	2.327	0.167	<0.001	0.021	0.008	<0.010	0.066	0.006	<0.001	0.120	0.085	=0.163	71	0.702	<0.001
Pinus	3.239	0.172	<0.001	0.033	0.016	=0.041	–0.040	0.023	=0.082	0.580	0.338	=0.093	56	0.223	<0.001
Picea	2.970	0.257	<0.001	–0.012	0.023	=0.615	0.056	0.020	=0.015	–0.009	0.367	=0.980	18	0.221	=0.093
Quercus	2.667	0.296	<0.001	–0.016	0.013	=0.224	0.001	0.000	<0.001	0.383	0.274	=0.171	41	0.626	<0.001
Dec Qu	3.132	0.260	<0.001	–0.028	0.014	=0.093	0.047	0.017	=0.026	0.480	0.264	=0.112	11	0.540	=0.038
Evergr Qu	0.870	0.617	=0.170	0.052	0.024	=0.039	0.077	0.010	<0.001	0.897	0.373	=0.023	30	0.749	<0.001

Table 7. Summary of regressions of standardized first-year mass loss (Stand(FML), %) against standardized mean annual temperature (Stand (MAT), °C), annual precipitation (Stand(APT), dm) and standardized litter nitrogen concentration (Stand (N), %) for combined broadleaf and coniferous litter (All litter), for the separate groups coniferous, broadleaf, deciduous broadleaf (Dec Br) and evergreen broadleaf (Evergr Br) as well as the genera *Pinus*, *Picea*, and *Quercus*, and the *Quercus* subgroups viz. deciduous *Quercus* (Dec Qu), and evergreen *Quercus* (Evergr Qu). The function used was Stand(FML) = D + A × Stand(MAT) + B × Stand(APT) + C × Stand (N)

Litter groups	Intercept			Stand(MAT)			Stand(APT)			Stand(N)			n	R^2_{adj}	p
	D	SE	p	A	SE	p	B	SE	p	C	SE	p			
All litter	0.094	0.049	=0.054	0.070 a	0.064	=0.277	0.666 b	0.067	<0.001	0.189 a	0.059	=0.002	200	0.578	<0.001
Coniferous[1)]	0.117	0.102	=0.255	0.327	0.159	=0.043	0.061	0.124	=0.626	0.199	0.130	=0.129	78	0.204	<0.001
Broadleaf[1)]	0.133	0.065	=0.044	–0.032 a	0.076	=0.671	0.802 b	0.078	<0.001	0.156 a	0.068	0.024	122	0.563	<0.001
Dec Br[2]	0.351	0.110	=0.003	–0.095 a	0.112	=0.402	0.913 b	0.150	<0.001	0.132 a	0.110	0.237	51	0.491	<0.001
Evergr Br[2)]	0.056	0.067	=0.411	0.197 a	0.074	=0.010	0.744 b	0.074	<0.001	0.107 a	0.076	0.163	71	0.702	<0.001
Pinus[3)]	0.147	0.121	=0.228	0.445 a	0.212	=0.041	–0.268 b	0.151	=0.082	0.280	0.163	0.093	56	0.223	<0.001
Picea[3)]	0.000	0.208	=1.000	–0.111	0.216	=0.615	0.599	0.217	=0.015	–0.005	0.217	0.980	18	0.221	=0.093
Quercus	0.153	0.103	=0.147	–0.138 a	0.112	=0.224	0.786 b	0.103	<0.001	0.151a	0.108	0.171	41	0.626	<0.001
Dec Qu[4)]	0.500	0.191	=0.035	–0.425 a	0.219	=0.093	0.701 b	0.248	=0.026	0.435 b	0.239	0.112	11	0.540	=0.038
Evergr Qu[4)]	0.068	0.094	=0.475	0.249 a	0.115	=0.039	0.768 b	0.096	<0.001	0.255 a	0.106	0.023	30	0.749	<0.001

Note: Tests for significant differences were made both within and between functions. Thus within an equation, different letters after the coefficients of Stand(MAT), Stand(APT) and Stand (N) indicate a significant difference. The levels of significant difference (t-test) are $p < 0.001$ for All litter, broadleaf, deciduous broadleaf, evergreen broadleaf, *Quercus*, and evergreen *Quercus*. For deciduous *Quercus* and *Pinus* the significance level was $p = 0.05$. Between functions we tested the coefficients of two variables of paired equations. 1) Significant differences ($p < 0.001$) were found between the groups coniferous and broadleaf as regards MAT and APT and at $p < 0.01$ for N. 2) Significant differences ($p < 0.001$) were found between deciduous and evergreen broadleaf litter as regards Intercept, MAT and APT. 3) Significant differences ($p < 0.001$) were found between *Pinus* and *Picea* for Intercept, MAT and N. 4) Significant differences were found between deciduous and evergreen *Quercus* litter ($p < 0.001$) as regards Intercept and MAT and at $p < 0.01$ for N.

the coefficient for Precipitation was c. 10 times that of Temperature. For the group 'coniferous' there were no significant differences, whereas for broadleaf litter there was a clearly higher effect of Precipitation. Thus was the effect of Precipitation for broadleaf litter significantly higher than both that of Temperature, which was negative, and N. The same pattern was seen for the separate groups of both deciduous and evergreen broadleaf and *Quercus* and the negative coefficient for Temperature was even more emphasized. Evergreen *Quercus* had a positive sign for Temperature but followed a pattern with significantly higher influence of Precipitation than of Temperature and N. Deciduous *Quercus* had a clearly negative coefficient for Temperature (–0.425) and it was significantly lower than the coefficient for Precipitation ($p<0.001$) and significantly lower than that for N (Table 7). *Pinus* had a somewhat different pattern with a significant difference between a positive Temperature and a negative Precipitation, whereas there was no significant difference between coefficients for Temperature and N. For *Picea* there was no significant difference between the coefficients.

For pairs of equations there were significant differences between the coefficients of the same variable. Thus, there were significant differences between the groups 'coniferous' and 'broadleaf' as regards all Temperature, Precipitation and N (Table 7). Further, there were significant differences ($p<0.001$) between deciduous broadleaf and evergreen broadleaf for Temperature and Precipitation and between *Pinus* and *Picea* as regards Temperature and N ($p<0.001$). There was also a significant difference between deciduous and evergreen *Quercus* ($p<0.001$) as regards Temperature and at $p<0.01$ for N.

3.5 First-Year Mass Loss at 100%

Several measured FML values reached 100%. The litter species with so high a mass-loss rate were broadleaf (mainly deciduous) and found in climates with Temperature in the range 14 to 28.1 °C and Precipitation between 14 and 28.2 dm (Fig. 1, Appendices A and B). The substrate chemistry ranged for lignin concentration between 10.8 and 22.4% and N concentrations between 0.94 and 3.1%.

4 Discussion

4.1 Differences in Variation of FML As Related to Climate and Litter-Quality Variables for Different Groups of Foliar Litter

Our comparison was conducted at four levels, (i) broadleaf vs. coniferous litter, (ii) deciduous broadleaf vs. evergreen broadleaf litter, (iii) genus level and (iv) within a genus (deciduous *Quercus* vs. evergreen *Quercus*). To our knowledge, such analyses of decay response have not been carried out in earlier work.

The clearly different responses among the groups to Temperature, Precipitation and N indicate different decomposition patterns among genera and groups of litter as regards temperature and precipitation regimes. We may thus note that only the decomposition of *Pinus* was promoted by Temperature (Table 3), whereas the other litter types were not. For *Picea* that was observed by Berg et al. (2000) in a climate gradient.

4.2 Effects of the Different Variables on First-Year Mass Loss of Leaf Litter – Implications for Climate Change

Climate affects the chemical composition of newly shed litter (Aerts 1997, Liu et al. 2006). Litter chemical composition as well as temperature and moisture in their turn influence the microbial activity. With an increase in annual average temperature, leaf litter N concentration increases at a regional scale (Liu et al 2006). The general acceptance is that climatic factors and litter quality play dominant roles on mass-loss rates along a broad climate gradient. Still, we may see that Temperature, Precipitation and N create a complicated pattern with very different responses among litter types and genera.

Our findings have two aspects of important implications. First, the changing of both Temperature and Precipitation will greatly influence FML; but with the changes of the same relative unit in Temperature and Precipitation, they displayed evidently different effects on FML, and in some cases the difference was significant (Table 7). This means that with global warming, we need to consider different effects of temperature and precipitation on FML. Second, the effects of Temperature, Precipitation, and litter quality on FML varied among groups of litter types. When using standardized variables (Temperature, Precipitation, and N) in multiple regressions, we found that the coefficients of standardized Temperature, standardized Precipitation and standardized N were 0.327, 0.061, and 0.199, respectively, for the coniferous model, showing that the effect of Temperature was much stronger than for Precipitation, but –0.032, 0.802 and 0.156, respectively, for the broadleaf model, suggesting that on a large scale and over several species the effect of temperature on FML may be negative or at least very close to zero. A clear indication is that on a large scale there is a strong difference in decomposition dynamics between coniferous and broadleaf litter with the decomposition of the former being more sensitive to temperature and relatively little to precipitation. We may note that the climate regions for these two groups are different for the majority of data and that the coniferous litter as a group has a somewhat shorter range in Temperature as compared to broadleaf litter and that the same applies to Precipitation (Fig. 1). Such differences in response to climate variables may result in corresponding very different responses among forests to climate change. Thus the initial decomposition of *Pinus* needle litter would be stimulated by an increasing temperature but that of *Picea* not.

Even within a genus, viz. between deciduous *Quercus* and evergreen *Quercus*, a clear difference was found between the coefficients. Thus were the coefficients of standardized (Temperature), standardized (Precipitation) and standardized (N) –0.425, 0.701, and 0.435, respectively, for deciduous *Quercus*, and 0.249, 0.768 and 0.255, respectively, for evergreen *Quercus*. A reasonable conclusion would be that as seen over a larger region, litter with properties that appear to be generated by local climate would not necessarily behave according to traditional and postulated patterns.

Generally, higher temperature means a longer period during which microbes can decompose litter (Liski et al. 2003). The effects described relate to the mass loss in the first year. Thus, the relative influence of changed Precipitation, Temperature and N relate to part of the decomposition process but it has been shown (Johansson et al. 1995) that in partially decomposed Scots pine needle litter the rate was so strongly controlled by the concentrations of lignin which increase in the decomposition process that the effect of temperature was negligible. That was in the temperature range of –1.0 to +10.0 °C.

4.3 Fit of Regression Models

When Meentemeyer (1978) investigated the effect of using annual evapotranspiration (AET), lignin concentration and the quotient AET-to-lignin as an interaction term, he found that AET alone accounted for 51% of the variance in observed decay rates, AET/lignin concentration added 19% and lignin concentration added 2% of the total (72%) variance accounted for.

Using an index which combined Temperature and summer drought based on only some temperature variables, Liski et al. (2003) could explain the first-year mass loss with an R^2 value of about 0.7 for Scots pine needle litter at a regional scale. When combined into a multiple regression, Temperature, Precipitation, and lignin-to-N ratio explained 73% of the variance in mass remaining for all sites and tissues (Moore et al. 1999). In the present study, R^2_{adj} reached a similar level (0.7) when climatic and litter-quality variables were employed as independent variables in multiple regression models, for single species even above 0.8 (Tables 6 and 7).

4.4 First-Year Mass Loss vs Possible Carbon Sequestration

With 100% mass loss of the leaf litter in one year or less and the assumption of one leaf generation per year, no remaining mass from foliar litter would accumulate on the forest floor and form an organic layer that sequesters carbon. Foliar litter is a major litter component and may determine the sequestration rate (cf. Berg et al. 2000). This means that any possible sequestration that would take place from the leaf litter component would be in the form of resistant compounds leached with water and precipitated in the mineral soil. No sequestration would take place to allow the formation of e.g. an O horizon. The litter species with so high a mass-loss rate were broadleaf (mainly deciduous) and found in subtropical and tropical climates with Temperature in the range 14 to 28.1 °C and Precipitation between 14 and 28.2 dm (Fig. 1, Appendices A and B). With these climate conditions and lignin concentration ranging between 10.8 and 22.4% and N concentrations between 0.94 and 3.1% we may distinguish a niche in which no sequestration takes place. Our reasoning does not mean that these litter types would be the only ones that do not sequester carbon in the form of a humus layer but rather that they would be litter types that clearly do not form any such layer.

We found 18 cases with such a high mass-loss rate. A main species that is found in this group is *Quercus*. Eleven further cases with mass loss between 95 and 100% included litter from the genera Populus and Shorea. In a given forest there may of course be other litter components from these species that sequester carbon.

5 Concluding Remarks

The differences in response of different litter species and types to different influencing factors (annual average temperature, annual precipitation and substrate quality) create a considerably more complicated pattern among litter species on a regional level than what has been expected. It thus appears that the response in decomposition to changes in the climate should be followed at least at the level of genus, possibly species. An ecological niche at which no carbon sequestration takes place in a humus layer encompassed subtropical and tropical broadleaf species.

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Appendix A. Data set for the first-year mass loss of leaf litter in Eurasian forests compiled based on the publications listed in Appendix B. Abbreviations: E, evergreen; D, deciduous; longit., longitude; latit, latitude; altit, altitude; temp, mean annual temperature; preci, annual precipitation; N, nitrogen.

Species/genus	E/D	Country	Longit (degree)	Latit (degree)	Altit (m)	Temp (°C)	Preci (mm)	Lignin (%)	N (%)	Mass loss (%)	Source
Broadleaf											
Betula	D	Finland	27.00	68.33		–0.4	508			33.0	Mikola 1954
Betula	D	Finland	27.00	68.03		–0.4	508			32.7	Mikola 1954
Betula	D	Finland	27.00	68.03		–0.4	508			28.0	Mikola 1954
Betula	D	Finland	27.00	66.33		–0.4	508			27.1	Mikola 1954
Betula	D	Finland	27.00	62.07		4.0	573			38.1	Mikola 1954
Betula	D	Finland	27.00	62.07		4.0	573			54.3	Mikola 1954
Betula	D	Finland	27.00	62.00		4.0	573	21.40		28.0	Mikola 1954
Betula pendula	D	Sweden	16.3	60.49	185	3.8	609	33.00	0.77	42.0	Berg and Ekbohm 1991
Alnus incana	D	Sweden	16.3	60.49	185	3.8	609	26.40	3.10	44.0	Berg and Ekbohm 1991
Betula pendula	D	Sweden	16.3	60.49	185	3.8	609	26.30	0.76	43.0	Berg and Staaf 1987
Populus tremula	D	Sweden	16.3	60.49	185	3.8	609		0.68	46.2	Berg et al. 200X
Betula	D	Finland	27.00	60.33		4.8	692			42.0	Mikola 1954
Betula	D	Finland	27.00	60.33		4.8	692			42.6	Mikola 1954
Betula pendula	D	Sweden	16.15	60.16	185	4.2	425	27.50	0.75	43.9	Johansson 1986
Fraxinus excelsior	D	England	–3.20	54.30		7.4	1527		1.55	90.0	Bocock 1964
Quercus petraea	D	England	–3.20	54.30		7.4	1527		0.77	42.0	Bocock 1964
Betula	D	Poland	23.67	52.68	175	6.6	626			55.1	Breymeyer 1991
Carpinus betulus	D	Poland	23.51	52.41		8.1	502		1.22	65.2	Dziadowiec 1987
Quercus robur	D	Poland	23.51	52.41		8.1	502		1.12	36.5	Dziadowiec 1987
Tilia cordata	D	Poland	23.51	52.41		8.1	502		1.47	59.6	Dziadowiec 1987
Carpinus betulus	D	Germany	8.50	49.10		10.1	614			86.0	Paulus et al. 1999
Carpinus betulus	D	Germany	8.50	49.10		10.1	614			76.0	Paulus et al. 1999
Fagus sylvatica	D	Germany	8.50	49.10		10.1	614			55.0	Paulus et al. 1999
Fagus sylvatica	D	Germany	8.50	49.10		10.1	614			60.0	Paulus et al. 1999
Betula costata	D	China	128.95	47.17	380	0.3	676		0.27	36.9	Wang and Wang 1991
Quercus mongolia	D	China	128.95	47.17	380	0.3	676		0.10	29.3	Wang and Wang 1991
Acer mono	D	China	128.95	47.17	380	0.3	676		0.20	64.4	Wang and Wang 1991
Tilia amurensis	D	China	128.95	47.17	380	0.3	676		0.24	41.3	Wang and Wang 1991
Tilia mandshurica	D	China	128.95	47.17	380	0.3	676		0.25	65.4	Wang and Wang 1991
Cornus mas	D	Hungary	20.00	47.00		9.9	589			68.4	Jakucs 1985
Quercus cerris	D	Hungary	20.00	47.00		9.9	589			36.1	Jakucs 1985
Quercus petraea	D	Hungary	20.00	47.00		9.9	589			36.8	Jakucs 1985
Acer campestre	D	Hungary	20.00	47.00		9.9	589			44.6	Jakucs 1985
Quercus mongolia	D	China	127.50	45.33		2.8	723			30.8	Wei and Zhou 1991

Fraxinus mandshurica	D	China	127.50	45.00		2.8	724			43.1	Shen et al. 1996
Quercus mongolica	D	China	127.50	45.00		2.8	724			28.3	Shen et al. 1996
Ulmus	D	China	127.50	45.00		2.8	724			46.8	Shen et al. 1996
Quercus mongolica var. *grossesrrata*	D	Japan	142.17	44.27	537.5	2.4	1339		0.77	63.5	Hardiwinoto et al. 1991
Castanea sativa	D	France	3.25	43.75	380	11.9	1212			27.7	Cortez 1998
Castanea sativa	D	France	3.25	43.75	520	12.8	1850			41.9	Cortez 1998
Castanea sativa	D	France	3.25	43.75	860	8.1	2355			41.7	Cortez 1998
Fagus sylvatica	D	France	3.25	43.75	380	11.9	1212			10.6	Cortez 1998
Fagus sylvatica	D	France	3.25	43.75	520	12.8	1850			32.2	Cortez 1998
Fagus sylvatica	D	France	3.25	43.75	860	8.1	2355			23.8	Cortez 1998
Quercus petraea	D	France	3.25	43.75	380	11.9	1212			17.6	Cortez 1998
Quercus petraea	D	France	3.25	43.75	520	12.8	1850			32.9	Cortez 1998
Quercus petraea	D	France	3.25	43.75	860	8.1	2355			30.1	Cortez 1998
Quercus pubescens	D	Italy	11.36	43.17		13.0	796	19.43	1.38	42.0	Cotrufo et al. 1999
Quercus cerris	D	Italy	11.88	42.41		15.6	825		0.78	39.0	van Wesemael 1993
Fagus sylvatica	D	Spain	–3.50	41.10	1375	8.7	1124		0.61	40.0	Pardo et al. 1997
Fagus sylvatica	D	Spain	–3.50	41.10	1375	8.7	1124		0.61	40.0	Pardo et al. 1997
Quercus pyrenaica	D	Spain	–3.50	41.10	1375	8.7	1124		0.84	50.0	Pardo et al. 1997
Quercus pyrenaica	D	Spain	–3.50	41.10	1375	8.7	1124		0.84	65.0	Pardo et al. 1997
Quercus pyrenaica	D	Spain	–6.00	40.50	1350	15.0	1500			22.0	Gallardo and Merino 1993
Castanea sativa	D	Spain	–6.00	40.50	1150	15.0	1500			30.0	Gallardo et al. 1995
Alnus glutinosa	D	Portugal	–8.50	40.20		14.4	1153		4.71	65.0	Pereira et al. 1998
Populus nigra	D	Portugal	–8.50	40.20		14.4	1153		2.00	49.0	Pereira et al. 1998
Acacia longifolia	D	Portugal	–8.50	40.20		14.4	1153		2.80	45.0	Pereira et al. 1998
Cistus libanotis	D	Spain	–6.20	37.12		16.7	500	3.90	0.41	15.0	Gallardo and Merino 1993
Fraxinus angustifolia	D	Spain	–6.20	37.12		16.7	500	5.10	0.93	42.0	Gallardo and Merino 1993
Quercus pyrenaica	D	Spain	–6.20	37.12		16.7	500	9.00	0.93	26.0	Gallardo and Merino 1993
Salix atrocinerea	D	Spain	–6.20	37.12		16.7	500	6.90	0.73	18.0	Gallardo and Merino 1993
Cistus libanotis	D	Spain	–6.20	37.10		16.7	500	8.80	0.41	17.0	Gallardo and Merino 1999
Fraxinus angustifolia	D	Spain	–6.20	37.10		16.7	500	10.50	0.93	43.0	Gallardo and Merino 1999
Quercus pyrenaica	D	Spain	–6.20	37.10		16.7	500	14.30	0.93	27.0	Gallardo and Merino 1999
Salix atrocinera	D	Spain	–6.20	37.10		16.7	500	18.10	0.73	18.0	Gallardo and Merino 1999
Fraxinus angustifolia	D	Spain	–5.58	36.50	432	16.2	1600	5.10	0.93	71.0	Gallardo and Merino 1993
Quercus pyrenaica	D	Spain	–5.58	36.50	432	16.2	1600	9.00	0.93	43.0	Gallardo and Merino 1993
Salix atrocinerea	D	Spain	–5.58	36.50	432	16.2	1600	6.90	0.73	32.0	Gallardo and Merino 1993
Quercus varibilis	D	China	119.23	31.98		15.7	979			58.0	Yu et al. 1994
Populus deltoides	D	India	79.35	30.17	300	22.5	1593			94.9	Lodhiyal and Lodhiyal 1997
Aesculus indica	D	India	79.47	29.40	2050	14.6	2822		1.10	100.0	Pandey and Singh 1982

Species/genus	E/D	Country	Longit (degree)	Latit (degree)	Altit (m)	Temp (°C)	Preci (mm)	Lignin (%)	N (%)	Mass loss (%)	Source
Populus deltoides	D	India	79.17	29.40		22.5	1464		0.97	65.0	Singh et al. 1993
Shorea robusta	D	India	79.17	29.40		22.5	1464		0.86	86.6	Singh et al. 1993
Lyonia ovalifolia	D	India	79.45	29.12		15.9	2005	15.80	0.80	96.3	Upadhyay 1993
Shorea robusta	D	India	79.45	29.12		15.9	2005	9.30	0.99	96.3	Upadhyay 1993
Populus deltoides	D	India	79.50	29.10	250	23.5	1400		1.09	96.0	Joshi et al. 1999
Alnus nepalensi	D	India	88.58	27.12	1855	11.7	3037			48.5	Sharma and Ambasht 1987
Alnus nepalensi	D	India	88.58	27.12	1855	11.7	3037			52.4	Sharma and Ambasht 1987
Alnus nepalensi	D	India	88.58	27.12	1855	11.7	3037			60.6	Sharma and Ambasht 1987
Alnus nepalensi	D	India	88.58	27.12	1855	11.7	3037			55.0	Sharma and Ambasht 1987
Alnus nepalensi	D	India	88.58	27.12	1855	11.7	3037			45.6	Sharma and Ambasht 1987
Azadirachta indica	D	India	82.00	24.16	350	30.2	1069		1.00	72.8	Singh et al. 1999
Dalbergia sissoo	D	India	82.00	24.16	350	30.2	1069		1.17	68.1	Singh et al. 1999
Shorea robusta	D	India	82.00	24.16	350	30.2	1069		0.72	47.1	Singh et al. 1999
Erythrophloem fodii	D	China	108.35	21.93	120	21.6	1340			50.5	Wu et al. 1990
Rain forest	E	China	108.82	18.67	200	22.1	2150			85.0	Lu and Liu 1994
Mountainous rain forest	E	China	108.82	18.67	850	22.1	2150			65.0	Lu. and Liu 1994
Ailanthus triphysa	D	India	76.01	11.30	60	28.1	2569	7.90	2.85	98.0	Jamaludheen and Kumar 1999
Pterocarpus marsupium	D	India	76.01	11.30	60	28.1	2569	22.40	2.57	100.0	Jamaludheen and Kumar 1999
Dillenia pentagyna	D	India	77.25	8.50	450	27.0	2338		1.04	100.0	Sundarapandian and Swamy 1999
Pterocarpus marsupium	D	India	77.25	8.50	450	27.0	2338		1.55	100.0	Sundarapandian and Swamy 1999
Shorea curtissii	D	Malaysia	100.28	5.53	185	27.6	2736			46.6	Gong and Ong 1983
Tectona grandis	D*	India	79.17	29.40		22.5	1464		1.03	71.6	Singh et al. 1993
Tectona grandis	D*	India	79.50	29.10	250	23.5	1400		0.98	90.0	Joshi et al. 1999
Tectona grandis	D*	India	76.53	10.53		27.5	2949			81.0	Sankaran 1993
Quercus ilex	E	France	3.25	43.75	380	11.9	1212			17.2	Cortez 1998
Quercus ilex	E	France	3.25	43.75	520	12.8	1850			24.7	Cortez 1998
Quercus ilex	E	France	3.25	43.75	860	8.1	2355			20.3	Cortez 1998
Arbutus unedo	E	Italy	11.88	42.41		15.6	825		1.19	26.5	van Wesemael 1993
Quercus suber	E	Italy	11.88	42.41		15.6	825		1.57	39.0	van Wesemael 1993
Arbutus unedo	E	Greece	23.50	40.50		16.1	449		0.72	37.0	Arianoutsou 1993
Quercus coccifera	E	Greece	23.50	40.50		16.1	449		0.73	33.0	Arianoutsou 1993
Quercus pyrenaica	E	Spain	–6.50	40.50		10.4	1580		1.06	39.0	Martin et al. 1997
Quercus pyrenaica	E	Spain	–6.50	40.50		12.9	720		1.34	40.0	Martin et al. 1997

Eucalyptus globulus	E	Portugal	–8.50	40.20		14.4	1153		2.11	55.0	Pereira et al. 1998
Quercus canariensis	E	Spain	–6.20	37.12		16.7	500	10.50	0.70	20.0	Gallardo and Merino 1993
Quercus coccifera	E	Spain	–6.20	37.12		16.7	500	11.20	0.91	18.0	Gallardo and Merino 1993
Quercus lusitanica	E	Spain	–6.20	37.12		16.7	500	11.50	0.91	10.0	Gallardo and Merino 1993
Quercus suber	E	Spain	–6.20	37.12		16.7	500	9.00	0.81	10.0	Gallardo and Merino 1993
Halimium halimifolium	E	Spain	–6.20	37.12		16.7	500	3.80	0.33	10.0	Gallardo and Merino 1993
Quercus canariensis	E	Spain	–6.20	37.10		16.7	500	15.60	0.70	21.0	Gallardo and Merino 1999
Quercus coccifera	E	Spain	–6.20	37.10		16.7	500	18.80	0.91	18.0	Gallardo and Merino 1999
Quercus lusitanica	E	Spain	–6.20	37.10		16.7	500	20.10	0.91	13.0	Gallardo and Merino 1999
Quercus suber	E	Spain	–6.20	37.10		16.7	500	18.10	0.81	12.0	Gallardo and Merino 1999
Halimium halimifolium	E	Spain	–6.20	37.10		16.7	500	8.90	0.33	12.0	Gallardo and Merino 1999
Quercus canariensis	E	Spain	–5.58	36.50	432	16.2	1600	10.50	0.70	36.0	Gallardo and Merino 1993
Quercus lusitanica	E	Spain	–5.58	36.50	432	16.2	1600	11.50	0.91	24.0	Gallardo and Merino 1993
Quercus suber	E	Spain	–5.58	36.50	432	16.2	1600	9.00	0.81	32.0	Gallardo and Merino 1993
Eucalyptus camaldulensis	E	India	77.87	30.47	640	29.0	2000		1.12	82.0	Bahuguna et al. 1990
Shorea robsta	E	India	77.87	30.47	640	29.0	2000		0.57	64.0	Bahuguna et al. 1990
Quercus leucotrichophora	E	India	79.30	30.40	1425	21.5	1298			69.0	Pant and Tiwari 1992
Myrica esculenta	E	India	79.45	30.17		15.9	2005	17.10	0.58	76.2	Upadhyay 1993
Rhododendron arboreum	E	India	79.45	30.17		15.9	2005	17.80	0.70	72.4	Upadhyay 1993
Leucaena leucocephala	E	India	76.85	29.97	250	13.2	800			98.0	Puri 1992
Quercus leucotrichophora	E	India	79.47	29.40	2050	14.6	2822		0.97	80.0	Pandey and Singh 1982
Ilex dipyrena	E	India	79.47	29.40	2050	14.6	2822		1.90	100.0	Pandey and Singh 1982
Quercus semecarpifolia	E	India	79.47	29.40		14.9	2100		1.01	56.2	Rawat and Singh 1995
Eucalyptus hybrid	E	India	79.17	29.40		22.5	1464		0.94	50.0	Singh et al. 1993
Quercus floribunda	E	India	79.47	29.40	2050	14.6	2822		1.07	69.0	Upadhyay 1990
Quercus glauca	E	India	79.47	29.35	1350	15.9	2005	10.77	0.94	100.0	Upadhyay 1990
Quercus floribunda	E	India	79.45	29.12		15.9	2005	17.30	0.97	64.1	Upadhyay 1990
Quercus glauca	E	India	79.45	29.12		15.9	2005	10.70	0.94	100.0	Upadhyay 1990
Quercus lanuginosa	E	India	79.45	29.12		15.9	2005	16.90	1.32	67.9	Upadhyay 1990
Quercus leucotrichophora	E	India	79.45	29.12		15.9	2005	16.70	1.15	73.9	Upadhyay 1990
Quercus leucotrichophora	E	India	79.45	29.12		15.9	2005	16.70	1.15	76.4	Upadhyay 1990
Quercus leucotrichophora	E	India	79.45	29.12		15.9	2005	16.70	1.15	87.1	Upadhyay 1990
Quercus leucotrichophora	E	India	79.45	29.12		15.9	2005	16.70	1.15	98.7	Upadhyay 1990
Quercus leucotrichophora	E	India	79.45	29.12		15.9	2005	16.70	1.15	97.0	Upadhyay 1990
Mallotus philippensis	E	India	79.45	29.12		15.9	2005	5.80	0.52	100.0	Upadhyay 1993
Eucalyptus hybrid	E	India	79.50	29.10	250	23.5	1400		0.78	65.0	Joshi et al. 1999
Grevellia robusta	E	India	79.50	29.10	250	23.5	1400		0.90	62.0	Joshi et al. 1999
Leucaena leucocephala	E	India	79.50	29.10	250	23.5	1400		2.25	100.0	Joshi et al. 1999
Castanopsis kawakamii	E	China	117.33	26.17		19.5	1547			85.0	Lian and Zhang 1998
Schima superba	E	China	117.33	26.17		19.5	1547			70.0	Lian and Zhang 1998

Species/genus	E/D	Country	Longit (degree)	Latit (degree)	Altit (m)	Temp (°C)	Preci (mm)	Lignin (%)	N (%)	Mass loss (%)	Source
Quercus dealbata	E	India	91.91	25.51	1900	25.0	1547	34.40	0.89	59.0	Arunachalam et al. 1998
Quercus dealbata	E	India	91.91	25.51	1900	25.0	1547	34.40	0.89	65.0	Arunachalam et al. 1998
Quercus griffithii	E	India	91.91	25.51	1900	25.0	1547	23.70	0.73	70.0	Arunachalam et al. 1998
Rhododendron arboeum	E	India	91.91	25.51	1900	25.0	1547	37.30	0.59	45.0	Arunachalam et al. 1998
Schima	E	India	91.91	25.51	1900	25.0	1547	25.10	1.03	70.0	Arunachalam et al. 1998
Castanopsis wattii	E	China	101.00	24.50		11.3	1931	33.60	1.30	62.0	Liu et al. 2000
Lithocarpus chintungensis	E	China	101.00	24.50		11.3	1931	47.86	1.29	50.0	Liu et al. 2000
Lithocarpus xylocarpus	E	China	101.00	24.50		11.3	1931	42.29	1.25	62.0	Liu et al. 2000
Sinarundinaria nitida	E	China	101.00	24.50		11.3	1931	42.55	1.08	42.0	Liu et al. 2000
Pongamia pinnata	E	India	82.00	24.16	350	30.2	1069		1.21	58.8	Singh et al. 1999
Schima wallicchii	E	China	108.35	21.93	120	21.6	1340			57.6	Wu et al. 1990
Casuarina equisetifolia	E	India	84.88	19.27		23.0	1310		0.99	35.6	Misra and Nisanka 1997
Artocarpus heterophyllus	E	India	76.01	11.30	60	28.1	2569	17.90	2.15	99.0	Jamaludheen and Kumar 1999
Artocarpus hirsutus	E	India	76.01	11.30	60	28.1	2569	31.40	1.73	99.0	Jamaludheen and Kumar 1999
Casuarina equisetifolia	E	India	76.01	11.30	60	28.1	2569	26.80	1.59	85.0	Jamaludheen and Kumar 1999
Emblica officinalis	E	India	76.01	11.30	60	28.1	2569	5.00	2.36	94.0	Jamaludheen and Kumar 1999
Acacia auriculiformis	E	India	76.01	11.30	60	28.1	2569	16.50	2.47	90.0	Jamaludheen and Kumar 1999
Leucaena leucocephala	E	India	76.01	11.30	60	28.1	2569	17.00	3.34	100.0	Jamaludheen and Kumar 1999
Paraserianthes falcataria	E	India	76.01	11.30	60	28.1	2569	28.10	3.06	100.0	Jamaludheen and Kumar 1999
Eucalyptus tereticornis	E	India	76.53	10.53		27.5	2949			51.0	Sankaran 1993
Paraserianthes falcataria	E	India	76.53	10.53		27.5	2949			75.0	Sankaran 1993
Cymbopogon citratus	E	India	78.20	9.90	133	29.0	575		1.11	60.0	Ilangovan and Paliwal 1996
Leucaena leucocephala	E	India	78.20	9.90	133	29.0	575		2.59	70.0	Ilangovan and Paliwal 1996
Aporosa lindleyana	E	India	77.25	8.50	450	27.0	2338		1.03	91.0	Sundarapandian and Swamy 1999
Artocarpus hirsutus	E	India	77.25	8.50	450	27.0	2338		1.01	90.0	Sundarapandian and Swamy 1999

Careya arborea	E	India	77.25	8.50	450	27.0	2338		1.07	100.0	Sundarapandian and Swamy 1999
Hopea parvifora	E	India	77.25	8.50	450	27.0	2338		1.60	100.0	Sundarapandian and Swamy 1999
Ixora brachiata	E	India	77.25	8.50	450	27.0	2338		1.25	100.0	Sundarapandian and Swamy 1999
Macaranga peltata	E	India	77.25	8.50	450	27.0	2338		1.24	100.0	Sundarapandian and Swamy 1999
Terminalia paniculata	E	India	77.25	8.50	450	27.0	2338		0.98	100.0	Sundarapandian and Swamy 1999
Vateria indica	E	India	77.25	8.50	450	27.0	2338		1.27	100.0	Sundarapandian and Swamy 1999
Xanthophyllum flavescens	E	India	77.25	8.50	450	27.0	2338		1.43	100.0	Sundarapandian and Swamy 1999
Calophyllum curtisii	E	Malaysia	100.27	5.52	185	27.6	2736			71.1	Gong and Ong 1983
Anisoptera curtisii	E	Malaysia	100.25	5.50	185	27.6	2736			46.2	Gong and Ong 1983
Conifers											
Pinus sylvestris	E	Finland	27.00	68.33		–0.4	508			31.1	Mikola 1954
Pinus sylvestris	E	Finland	27.00	68.33		4.8	692			34.6	Mikola 1954
Pinus sylvestris	E	Sweden	19.23	68.23	370	–0.7	470			13.5	Breymeyer a.i.
Pinus sylvestris	E	Finland	27.00	68.07		4.0	573			35.3	Mikola 1954
Pinus sylvestris	E	Finland	27.00	68.03		–0.4	508			27.3	Mikola 1954
Pinus sylvestris	E	Finland	27.00	68.03		–0.4	508			25.6	Mikola 1954
Pinus sylvestris	E	Sweden	20.18	66.53		0.6	470	24.40	0.32	17.9	Johansson 1994
Pinus sylvestris	E	Finland	27.00	66.33		–0.4	508			38.0	Mikola 1954
Pinus sylvestris	E	Sweden	20.11	66.32	280	–0.5	490	24.40	0.32	17.9	Johansson 1986
Picea abies	E	Sweden	20.02	66.22	405	–1.7	469	33.50	0.57	20.1	Berg et al. 2000
Pinus sylvestris	E	Sweden	20.53	66.08	58	1.3	650	25.50	0.41	11.1	Berg et al. 1991
Pinus sylvestris	E	Sweden	20.62	65.78		0.2	516	27.10	0.29	19.8	Johansson 1994
Pinus sylvestris	E	Sweden	20.62	65.78		0.2	516	27.30	0.30	25.9	Johansson 1994
Pinus sylvestris	E	Sweden	20.62	65.78		0.2	516	26.80	0.32	30.7	Johansson 1994
Pinus sylvestris	E	Sweden	20.37	65.47	135	1.0	700	27.10	0.29	19.8	Berg et al. 1991
Pinus sylvestris	E	Sweden	14.47	63.22		2.9	532	26.20	0.41	36.4	Johansson 1994
Picea abies	E	Sweden	14.28	63.13	325	2.3	460	28.80	0.40	32.8	Berg et al. 2000
Pinus sylvestris	E	Sweden	14.28	63.13	325	2.1	460	26.20	0.41	36.4	Johansson 1986
Pinus sylvestris	E	Finland	27.00	62.07		4.0	573			34.2	Mikola 1954
Pinus sylvestris	E	Finalnd	24.57	62.07		4.0	573			13.4	Paavilainen 1980
Pinus sylvestris	E	Finalnd	24.57	62.07		4.0	573			16.5	Paavilainen 1980
Pinus sylvestris	E	Finalnd	24.57	62.07		4.0	573			15.3	Paavilainen 1980

Species/genus	E/D	Country	Longit (degree)	Latit (degree)	Altit (m)	Temp (°C)	Preci (mm)	Lignin (%)	N (%)	Mass loss (%)	Source
Pinus sylvestris	E	Finalnd	24.57	62.07		4.0	573			17.0	Paavilainen 1980
Pinus sylvestris	E	Finalnd	24.57	62.07		4.0	573			17.9	Paavilainen 1980
Pinus sylvestris	E	Finalnd	24.57	62.07		4.0	573			13.9	Paavilainen 1980
Pinus sylvestris	E	Finland	24.32	61.67	140	2.9	576			26.0	Mälkönen 1974
Pinus sylvestris	E	Sweden	16.50	60.82	185	3.8	607			28.1	Breymeyer 1991
Pinus contorta	E	Sweden	13.62	60.63	400	6.2	624	39.00	0.37	25.0	Berg and Lundmark 1987
Pinus sylvestris	E	Finland	13.62	60.63	400	6.2	624	29.00	0.41	31.0	Paavilainen 1980
Pinus contorta	E	Sweden	13.73	60.55	375	6.2	624	25.00	0.37	31.0	Berg and Lundmark 1987
Picea abies	E	Sweden	16.01	60.55	350	3.1	745	34.40	0.61	21.0	Berg et al. 2000
Pinus sylvestris	E	Finland	13.73	60.55	375	6.2	624	25.00	0.43	30.0	Paavilainen 1980
Pinus sylvestris	E	Finland	23.88	60.52	135	3.7	545			34.0	Mälkönen 1974
Pinus sylvestris	E	Finland	23.85	60.52	125	3.7	545			28.0	Mälkönen 1974
Pinus sylvestris	E	Sweden	16.30	60.49	185	3.8	609	22.50	0.40	26.5	Berg et al. 1991
Pinus sylvestris	E	Sweden	13.37	60.38	400	2.4	612	30.00	0.46	35.9	Berg et al. 1991
Pinus sylvestris	E	Sweden	13.37	60.38	400	2.4	612	29.30	0.36	31.0	Berg et al. 1991
Pinus contorta	E	Sweden	13.37	60.38	400	2.4	612	39.10	0.38	24.6	Berg et al. 1991
Pinus contorta	E	Sweden	13.37	60.38	400	2.4	612	35.70	0.37	30.3	Berg et al. 1991
Pinus sylvestris	E	Sweden	13.34	60.35	435	2.1	480	24.30	0.47	35.2	Berg et al. 1991
Pinus contorta	E	Sweden	13.34	60.35	435	2.1	480	36.50	0.42	29.5	Berg et al. 1991
Pinus sylvestris	E	Finland	27.00	60.33		4.8	692			35.8	Mikola 1954
Pinus sylvestris	E	Sweden	13.44	60.33	375	2.8	600	28.50	0.41	30.4	Berg et al. 1991
Pinus sylvestris	E	Sweden	13.44	60.33	375	2.8	600	26.50	0.44	38.2	Berg et al. 1991
Pinus contorta	E	Sweden	13.44	60.33	375	2.8	600	38.90	0.34	22.2	Berg et al. 1991
Pinus contorta	E	Sweden	13.44	60.33	375	2.8	600	36.60	0.40	28.3	Berg et al. 1991
Picea abies	E	Sweden	16.15	60.16	185	4.2	425	34.40	0.63	25.9	Berg et al. 2000
Picea abies	E	Sweden	16.15	60.16	185	4.2	425	31.10	0.54	23.7	Berg et al. 2000
Picea abies	E	Sweden	17.28	60.14	40	4.4	580	33.80	1.00	27.9	Berg et al. 2000
Picea abies	E	Finland	27.00	60.00		4.0	573	19.50	0.40	27.4	Mikola 1954
Pinus peuce	E	Finland	27.00	60.00		4.0	573			20.5	Mikola 1954
Pinus sylvestris	E	Finland	27.00	60.00		4.0	573			30.0	Mikola 1954
Pinus sylvestris	E	Sweden	16.22	59.82		3.8	609	25.50	0.45	36.9	Johansson 1994
Pinus sylvestris	E	Sweden	17.27	59.52		6.6	555	22.60	0.38	38.1	Johansson 1994
Picea abies	E	Sweden	16.33	59.49	63	5.1	550	28.60	0.54	25.6	Berg et al. 2000
Pinus sylvestris	E	Sweden	16.33	59.49	63	5.1	550	25.50	0.45	36.9	Johansson 1986
Pinus sylvestris	E	Sweden	14.33	59.44	220	5.4	660	24.90	0.52	41.2	Berg et al. 1991
Pinus contorta	E	Sweden	14.33	59.44	220	5.4	660	36.20	0.50	28.0	Berg et al. 1991
Pinus sylvestris	E	Sweden	17.16	59.31	30	5.2	470	27.70	0.38	35.2	Berg et al. 1991

Picea abies	E	Sweden	17.16	59.31	30	5.2	470	27.70	0.53	26.9	Berg et al. 2000
Pinus sylvestris	E	Sweden	17.27	59.12		6.6	555	24.60	0.41	43.7	Johansson 1994
Pinus sylvestris	E	Sweden	15.44	59.07	70	5.5	560	24.60	0.41	43.7	Berg et al. 1991
Picea abies	E	Sweden	15.44	59.07	70	5.5	560	31.50	0.58	26.8	Berg et al. 2000
Picea abies	E	Sweden	15.44	59.07	70	5.5	560	28.20	0.58	19.3	Johansson 1984
Pinus sylvestris	E	Sweden	15.85	58.55		6.2	538	21.90	0.39	42.0	Johansson 1994
Pinus sylvestris	E	Sweden	13.65	58.47		6.2	538	25.50	0.41	35.2	Johansson 1994
Pinus sylvestris	E	Sweden	15.51	58.33	58	6.1	520	28.20	0.39	41.9	Berg et al. 1991
Picea abies	E	Sweden	15.51	58.33	58	6.1	520	28.20	0.45	19.3	Berg et al. 2000
Pinus sylvestris	E	Sweden	13.39	58.28	128	5.6	530	25.50	0.41	35.2	Berg et al. 1991
Picea abies	E	Sweden	13.39	58.28	128	5.6	530	31.40	0.51	30.3	Berg et al. 2000
Pinus sylvestris	E	Sweden	13.28	58.10		6.2	538	34.80	0.38	36.3	Johansson 1994
Pinus sylvestris	E	Sweden	14.13	58.07		6.2	930	23.10	0.47	30.0	Johansson 1994
Picea abies	E	Sweden	13.17	58.06	170	5.5	675	33.50	0.51	27.8	Berg et al. 2000
Pinus sylvestris	E	Sweden	13.17	58.06	170	5.5	675	34.80	0.38	36.3	Johansson 1986
Pinus sylvestris	E	Sweden	14.08	58.04	245	4.9	650	28.90	0.47	30.2	Johansson 1986
Pinus sylvestris	E	Sweden	13.25	56.60		7.9	553	28.90	0.43	42.2	Johansson 1994
Picea abies	E	Sweden	13.05	56.42	80	7.4	747	33.30	0.50	24.3	Berg et al. 2000
Pinus sylvestris	E	Sweden	13.15	56.36	135	6.8	1070	28.10	0.43	42.2	Berg et al. 1991
Picea abies	E	Sweden	13.15	56.36	135	6.8	1070	34.20	0.54	28.8	Berg et al. 2000
Picea abies	E	Sweden	14.35	56.26	140	5.7	660	34.70	0.55	25.2	Berg et al. 2000
Pinus sylvestris	E	Poland	22.00	54.17	200	6.7	579			36.9	Breymeyer 1991
Pinus sylvestris	E	Poland	23.67	52.68	175	6.6	626			34.9	Breymeyer 1991
Pinus sylvestris	E	Germany	13.23	52.47		8.9	581		1.10	50.0	Kratz 1991
Pinus sylvestris	E	Germany	13.23	52.47		8.9	581		1.10	50.0	Kratz 1991
Pinus sylvestris	E	Poland	20.42	50.50	200	7.6	595			40.2	Breymeyer 1991.
Pinus koraiensis	E	China	128.95	47.17	380	0.3	676		0.14	15.0	Wang and Wang 1991
Pinus koraiensis	E	China	128.95	47.17	380	0.3	676		0.14	20.0	Wang and Wang 1991
Pinus koraiensis	E	China	128.95	47.17	380	0.3	676		0.14	22.0	Wang and Wang 1991
Pinus koraiensis	E	China	128.95	47.17	380	0.3	676		0.14	25.0	Wang and Wang 1991
Pinus koraiensis	E	China	127.50	45.00		2.8	724			20.4	Shen et al. 1996
Pinus sylvestris	E	China	127.50	45.00		2.8	724			34.7	Shen et al. 1996
Picea glehnii	E	Japan	142.17	44.25	537.5	2.4	1339		0.63	49.0	Hardiwinoto et al. 1991
Abies sachalinensis	E	Japan	142.17	44.25	537.5	2.4	1339		0.73	27.0	Hardiwinoto et al. 1991
Pinus pinater	E	Italy	11.88	42.41		15.6	825		0.57	16.0	van Wesemael 1993
Pinus sylvestris	E	Spain	–5.04	40.58		12.1	364			30.0	Santa Reigina et al. 1986
Pinus sylvestris	E	Spain	–6.00	40.50	1550	15.0	680			18.0	Gallardo et al. 1995
Pinus tabulaeformis	E	China	116.32	39.95	260	11.8	619	21.31	0.54	23.2	Hu et al. 1986
Pinus tabulaeformis	E	China	116.32	39.95	220	11.8	630		0.41	25.0	Yao 1989
Pinus pinea	E	Italy	16.56	39.40	1300	9.0	1225		0.62	10.0	Fioretto et al. 1998.

Species/genus	E/D	Country	Longit (degree)	Latit (degree)	Altit (m)	Temp (°C)	Preci (mm)	Lignin (%)	N (%)	Mass loss (%)	Source
Pinus sylvestris	E	Italy	16.56	39.40	1300	9.0	1225		0.49	15.0	Fioretto et al. 1998.
Pinus halepensis	E	Spain	–1.10	38.20		18.0	304			28.5	Pastor 1992
Chamaecyparis obtusa	E	Japan	138.90	35.70	1250	7.4	1745			25.0	Kawahara et al. 1981
Larix leptolepis	E	Japan	138.90	35.70	1250	7.4	1745			25.0	Kawahara et al. 1981
Chamaecyparis obstusa	E	Japan	135.05	35.07	200	15.0	1678			30.0	Takeda 1995
Cunninghamia lanceolata	E	China	119.23	31.98		15.7	979			21.0	Yu et al. 1994
Pinus taeda	E	China	119.23	31.98		15.7	979			42.0	Yu et al. 1994
Cedrus deodara	E	India	79.47	29.40	2050	14.6	2822		0.93	62.0	Pandey and Singh 1982
Cupressus torulosa	E	India	79.47	29.40	2050	14.6	2822		0.83	51.0	Pandey and Singh 1982
Pinus roxburghii	E	India	79.45	29.12		15.9	2005	23.40	0.67	51.3	Upadhyay 1993
Pinus roxburghii	E	India	79.50	29.10	250	23.5	1400		0.63	60.0	Joshi et al. 1999
Cunninghamia lanceolata	E	China	109.75	26.83	400	16.8	1300		0.92	41.6	Tian and Zhao 1989
Cunninghamia lanceolata	E	China	109.75	26.83	400	16.8	1300			40.3	Tian and Zhao 1989
Cunninghamia lanceolata	E	China	109.75	26.83	400	16.8	1300			55.5	Tian and Zhao 1989
Pinus kesiya	E	India	91.91	25.51	1900	25.0	1547	43.20	0.98	65.0	Arunachalam et al. 1998
Cunninghamia lanceolata	E	China	108.35	21.93	120	21.6	1340			20.2	Wu et al. 1990
Pinus massoniana	E	China	108.35	21.93	120	21.6	1340			42.5	Wu et al. 1990

Appendix B. List of literature for the data set of the mass-loss rate of leaf litter in Eurasian forests

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