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*Regular research paper*

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# PROCESSES OF LITTER FALL AND DECOMPOSITION: BOREAL-TEMPERATE TRANSECT STUDIES OF PINE ECOSYSTEMS

ABSTRACT: The processes of litter production and decomposition were studied in pine and mixed pine forests (10 sites) distributed along the N-S transect in Europe. The transect stretched from 70°N in Northern Finland and Norway to 50°N in Southern Poland. Mean annual temperatures change regularly along the transect from –1.9 to +7.4°C, while precipitation does not show any distinct pattern. Annual production and decomposition of litter are stimulated by warming. The primary factors governing the rates of both processes are related to thermic regime, most frequently to the long-term temperatures registered in the meteorological stations in the vicinity of sites. Correlation between decomposition rate and temperature ($R^2$) range from 0.75 to 0.93, between decomposition rate and latitude from 0.72 to 0.80, and between decomposition rate and precipitation from 0.52 to 0.63 (in the last case only correlations with long-term precipitation are significant). Correlation coefficients $R^2$ between litterfall and temperature range from 0.53 to 0.80, between litterfall-latitude from 0.72 to 0.80, and between litterfall-precipitation from 0.52 to 0.63 (significant only for long-term precipitation). With increasing temperature decomposition rates increase from about 0.09 $g.g^{-1}.y^{-1}$ (needles 0.13 $g.g^{-1}.y^{-1}$, wood 0.06 $g.g^{-1}.y^{-1}$) in the North to about 0.32 $g.g^{-1}.y^{-1}$ (needles 0.41 $g.g^{-1}.y^{-1}$, wood 0.18 $g.g^{-1}.y^{-1}$) in the South. Litterfall increases from 103.19 $g.m^{-2}.y^{-1}$ (in this needles 56.73 $g.m^{-2}.y^{-1}$, wood 45.59 $g.m^{-2}.y^{-1}$) in the North, to about 419.36 $g.m^{-2}.y^{-1}$ (needles 203.95 $g.m^{-2}.y^{-1}$, wood 203.56 $g.m^{-2}.y^{-1}$) in the South. OM annual accumulation increases southward, ranging from about 100 (North) to about 370 (South) grams per $m^2$. Accumulation is strongly connected with air temperatures on the sites (correlation coefficients ($R^2$) at around 0.9).

KEY WORDS: litter production-decomposition, effects of climate warming, pine ecosystem functioning, OM accumulation

## 1. INTRODUCTION

Although the relationship between the rate of decomposition of forest litter and climate is generally documented or predicted by modelling efforts, the geographical patterns of relationships to climatic conditions are not defined clearly. In the older literature two characteristics, actual evapotranspiration (AET) and average annual temperature, were treated as the most important factors determining the rate of decomposition of organic matter, which chemical composition is held constant (Meentemeyer and Berg 1986). Meentemeyer (1978, 1984) and Dyer (1986) formulated an empirical regression model allowing forest litter decomposition rates to be predicted using only two parameters: AET and lignin concentration in the substrate. McClaugherty and Berg (1987) show that in the late stages of decomposition it is mainly the lignin concentration that suppresses the rate of the decay process.

Studies on litter decomposition, performed under the FERN programme (Forest European Research Network) use "unified litter" i.e. needles from one site over an extensive network of 39 sites between northern Finland and Madrid or Istanbul along the N-S transect, and between Budapest, Belgrade and Lisbon along the W-E transect, showed a strong correlation between rates of litter decay and such climatic factors as AET, average July temperature and average annual temperature. Approximately 70% of geographical variability in litter decomposition rate was explained by the combination of these three factors. However, when the subsets of sites belonging to the North European, Central European, Atlantic or Mediterranean climatic zones were analysed separately (Berg *et al.* 1984), the strength of the correlation appeared to differ, and was negligible for Central Europe (Berg *et al.* 1993). A much stricter approach was adopted by Breymeyer (1991a, b), who minimised all factors driving decomposition rate other than climate by selecting only pure Scots pine forests growing on similar sediments and of similar age as well as position in phytosociological classification. As a result, it was possible to demonstrate regular increase in annual rate of litter decomposition along a transect running North (61°14') to South (50°30'). The calculated increase in annual litter decomposition rate was between roughly 1% (woody parts) and 3% (needles) for every 1°C of increase in average annual temperature.

## 2. STUDY SITES

Nine study sites distributed along N-S transect are introduced in the papers of Breymeyer (2003) and Solon (2003) in this volume. Those are pine or mixed pine forests growing on sandy soils (Degórski 2003, in this volume). According to the Braun-Blanquet classification they all belong to Vaccinio-Piceetea class of forests common in Europe, and specially well developed in the Central – North – Eastern parts of the Continent (compare the map from Solon 2003, in this volume).

All sites are placed within a long (2000 km), lowland stripe of land delimited by meridians 22–29°E. The stripe covers 20° of northern latitude (from 50°N in Southern Poland to 70°N in Northern Finland and Norway, Table 1).

The regularly southward growing long-term average annual temperatures were used as the basic information, characterizing thermic conditions for sites (the difference between the extreme sites is of the order of 9°C). For eight sites the mean temperatures for 7–10 years from the decade of the 1990s were available, as well as the temperatures in the study years (1997, 1998, 1999) (Table 1).

The similarly collected precipitation data do not show so regular changes with latitude (Table 1).

Table 1. Geographic position, annual temperature, precipitation from long-term climatic measurements and mean values for mixed litter decomposition (DECO) and total litterfall (LITF) for 10 sites on N-S transect

| Site | Geographic position | Annual temperature (°C) | Annual precipitation (mm) | DECO $g.g^{-1}.y^{-1}$ | LITF $g.m^{-2}.y^{-1}$ |
|---|---|---|---|---|---|
| N1 | N 70°08'; E 24°47' | 0.6 | 345.0 | | |
| FN1 | N 69°44'; E 27°01' | -1.9 | 414.1 | 0.09 | 103.19 |
| FN2 | N 64°43'; E 26°01' | 1.9 | 510.6 | 0.16 | 183.93 |
| FN3 | N 61°39'; E 29°16' | 3.3 | 579.8 | 0.19 | 167.44 |
| ES1 | N 58°18'; E 24°59' | 5.2 | 733.5 | 0.22 | 452.96 |
| LT1 | N 56°37'; E 24°53' | 5.3 | 683.0 | 0.31 | 412.25 |
| LI1 | N 55°25'; E 26°01' | 5.8 | 641.6 | 0.22 | 479.07 |
| PL1 | N 53°52'; E 23°18' | 6.4 | 582.9 | 0.25 | 357.76 |
| PL2 | N 52°55'; E 23°27' | 6.8 | 586.1 | 0.28 | 442.31 |
| PL3 | N 50°28'; E 22°59' | 7.4 | 580.0 | 0.32 | 419.36 |

Table 2. Correlation of litterfall ($g.m^{-2}.y^{-1}$) and decomposition ($g.g^{-1}.y.^{-1}$) rates with climatic factors (different periods) and latitude. Single DECO and LITF measurements on 9 sites from the years 1997–1999 are correlated with temperature and precipitation measurements for following time spans: long-term (usually above 30 years) for all sites; 7–10 years annual means from decade of 90s for majority of stands; study years, i.e. 1997–1999 annual means – for majority of sites

| Process | | Correlation coefficients | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | with latitude | with mean annual temperature | | | with mean annual precipitation sum | | |
| | | | years 1997–1999 | last 7–10 years | long-term | years 1997–1999 | last 7–10 years | long-term |
| Litter fall | | | | | | | | |
| needles | r | -0.43 | 0.481 | 0.46 | 0.44 | 0.37 | 0.43 | 0.45 |
| | n | 422 | 326 | 366 | 422 | 326 | 386 | 422 |
| | p | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 |
| wood | r | -0.49 | 0.54 | 0.53 | 0.50 | 0.21 | 0.44 | 0.50 |
| | n | 309 | 246 | 269 | 309 | 246 | 281 | 309 |
| | p | 0 | <0.0001 | <0.0001 | <0.0001 | <0.001 | <0.0001 | <0.0001 |
| mixed (total) | r | -0.67 | 0.71 | 0.71 | 0.67 | 0.36 | 0.56 | 0.64 |
| | n | 309 | 246 | 269 | 309 | 246 | 269 | 309 |
| | p | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 |
| Decomposition | | | | | | | | |
| needles | r | -0.88 | 0.88 | 0.89 | 0.88 | 0.33 | 0.70 | 0.72 |
| | n | 360 | 270 | 310 | 360 | 270 | 330 | 360 |
| | p | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 |
| wood | r | -0.37 | 0.46 | 0.40 | 0.37 | 0.33 | 0.38 | 0.29 |
| | n | 185 | 140 | 160 | 185 | 140 | 170 | 185 |
| | p | 0 | <0.001 | <0.0001 | <0.0001 | <0.001 | <0.0001 | <0.001 |
| mixed (total) | r | -0.61 | 0.62 | 0.62 | 0.59 | 0.14 | 0.42 | 0.37 |
| | n | 310 | 260 | 260 | 310 | 220 | 280 | 310 |
| | p | <0.0001 | <0.0001 | <0.0001 | <0.0001 | 0.037 | <0.0001 | <0.0001 |

r - correlation coefficient, n - number of samples, p - level of significance

## 3. FIELD AND LABORATORY METHODS

The plots for the measurement of litterfall and decomposition were located in the central parts of sites; in the centre of a homogeneous fragment of forest of roughly 400 $m^2$ the decomposition area was established. The weighted portions of litter, dried in 60°C to constant weight were enclosed in the bags 10x10cm, made of 1 mm nylon netting. Bags were then incubated for one year. The plots, on which the bags were placed ,were cleaned of moss and small shrubs to ensure that the exposed litter is in contact with the upper soil layer. At each site 60 litter bags were simultaneously placed. Twenty bags with 1 g each of mixed litter (i.e. the same composition as it was collected in the same site during last year), 20 bags with 1 g of pine needles each, 10 with a single cone in each and 10 with 1 g of small twigs. The exposure of litter bags always began in autumn (October), when maximum of annual litterfall occurred. Samples were collected after one year (next October), when the bags for the next year exposure were being laid out.

Table 3. Significant correlations of litterfall (g.m$^{-2}$.y$^{-1}$) and decompostion (g.g$^{-1}$.y$^{-1}$) with climatic factors and latitude. Means from 3 years measurements on 9 sites (r, n, p see Table 2).

| Process | | Correlation coefficients | | | | | |
|---|---|---|---|---|---|---|---|
| | | | with annual temperature | | | with precipitation sums | |
| | | with latitude | years 1997–1999 | last 7–10 years | long-term | last 7–10 years | long-term |
| Litter fall (LITF) | | | | | | | |
| needles | r | --0.82 | 0.81 | 0.84 | 0.83 | 0.70 | 0.77 |
| | n | 25 | 20 | 22 | 25 | 22 | 25 |
| | p | .0001 | <0.0001 | <0.0001 | <0.0001 | 0.0003 | <0.0001 |
| wood | r | −0.72 | 0.76 | 0.76 | 0.73 | 0.59 | 0.71 |
| | n | 25 | 20 | 22 | 25 | 22 | 25 |
| | p | <0.0001 | 0.0001 | <0.0001 | <0.0001 | 0.004 | 0.0001 |
| mixed (total) | r | –0.84 | 0.86 | 0.87 | 0.85 | 0.69 | 0.79 |
| | n | 25 | 20 | 22 | 25 | 22 | 25 |
| | p | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 |
| Decomposition (DECO) | | | | | | | |
| needles | r | −0.96 | 0.93 | 0.96 | 0.96 | 0.74 | 0.77 |
| | n | 22 | 17 | 19 | 22 | 19 | 22 |
| | p | <0.0001 | <0.0001 | <0.0001 | <0.0001 | 0.0003 | <0.0001 |
| wood | r | −0.54 | 0.60 | 0.59 | 0.54 | 0.52 | |
| | n | 22 | 17 | 19 | 22 | 19 | |
| | p | 0.0093 | 0.0109 | 0.0078 | 0.0089 | 0.0231 | |
| mixed (total) | r | −0.89 | 0.85 | 0.86 | 0.86 | 0.63 | 0.64 |
| | n | 19 | 14 | 16 | 19 | 16 | 19 |
| | p | <0.0001 | 0.0001 | <0.0001 | <0.0001 | 0.0093 | 0.0031 |

After collection from the forest, the litterbags were transferred to the laboratory and cleaned of soil and plants overgrowing the netting to leave litter which was then dried (60°C) to constant weight and weighted. The loss of mass is the measure of litter decomposition rate.

The plots for measurement of decomposition were surrounded by plots for measurement of litter fall. There were four such plots of roughly 1 m$^2$ in each site, and these were cleaned of vegetation and then covered with an even layer of scattered sand. The plots were in the W, N, E and S directions at the distance of about 10 m from the central decomposition plot. Every year in autumn the litter was collected from these plots with the aid of a ring with an area of 0.1 m$^2$. The total of 12–15 such circular litter samples were collected from each stand, with the litter being taken to the laboratory for cleaning, drying (60°C) and weighting. The litter was then separated into needles, cones and twigs; the natural composition of litter collected from plots is termed mixed litter.

In the last year of field studies (October 2000–October 2001) the so called „standard litter" was used for incubation in the sites to compare the decomposition of local needle litters with decomposition of needles coming from pine trees selected at one pine forest stite in the Kampinos National Park in the vicinity of Warsaw.

The content of Carbon in all the litter fractions from five sites was evaluated using the Tiurin method (three replications for each litter sample).

In order to evaluate the share of mineral fraction in the litter samples they were burned in the Thermolyne muffle stove in 700°C.

The content of lignin was evaluated according to the Tappi modification of the Klason method (Cichocka and Sapek-Dźwigała, 2002).

The number of samples collected during the three field expeditions is shown in Table 2.

Generally, for each site, each litter fraction, and each climatic factor there were more than one hundred samples collected (in some cases even more than four hundred) . However, for further calculations the mean values of litter biomass per site, litter kind and factor were used (Table 3), and on this data set the ecological analyses of relations between the processes studied and the environmental factors were carried out.

# 4.RESULTS

## 4.1. LITTER COMPOSITION

The amount of organic Carbon in litter from 5 study sites ranges from 49% to 52% of biomass of the woody fraction and from 52% to 54% of biomass of the needles (Table 4).

The share of mineral fraction in collected litter is small; for woody fractions it ranges from 1.6% to 2.6%, for needles – from 1.8% to 2.7%.

The content of lignin in the litters ranges from 33.4% (SD=2.9) for cones to 34.3% (SD=0.4) for needles. The standard litter from site Kampinos National Park has, in comparison, lower content of lignin, equal to 27.7% (Table 4). The content of lignin in the same standard litter incubated for one year on transect sites increases to 46.1% (SD = 4.5).

Table 4. Percent increase in litter lignin content after one year incubation. Lignin content in standard newly shed needle litter 0 (KAMP) and in the same litter after annual decomposition (DECO) at N-S transect sites

| | Site | Lignin content (%) |
|---|---|---|
| O (KAMP) | | 27.7 |
| DECO | N1 | 38.8 |
| | FN1 | 38.3 |
| | FN2 | 47.6 |
| | FN3 | 47.6 |
| | ES1 | 50.3 |
| | LT1 | 48.1 |
| | LI1 | 48.5 |
| | PL2 | 49.7 |
| | PL3 | 46.2 |
| Average DECO | | 46.1 |
| SD | | ± 4.56 |

0 (KAMP) – newly shed standard litter from the site Kampinos National Park, Central Poland.

None of above described chemical litter characteristics changes significantly with latitude or temperature along the N-S transect.

## 4.2. LITTER FALL IN GRADIENT OF CLIMATIC CONDITIONS

The pattern of dependence of litter production (LITF) upon the geographical and climatic conditions is presented in the form of regression curves in Figs 1, 2 and 3. Under each regression equation (linear or exponential) the corresponding $R^2$ values are placed. Both equations and lines of regression are presented if both relationships are significant, in this way the user of our models can select the better fitting version. The significance level of 0.05 was adopted.

The biomass of all the three kinds of litter (woody litter, needle litter, mixed litter) is well correlated with temperature changes along the transect sites (Fig.1). Correlation coefficients are high in all analysed cases; the highest one connect the biomass of total (mixed) litter and the changes of temperature from the 1990s (7–10 year means).

Figure 1 introduces both linear and exponential relationships between LITF and temperatures on the sites. The two lines display suffciently high correlation to be considered significant, although it appears that the values of $R^2$ for the exponential curves are somewhat higher. The relations linking LITF with precipitation are much weaker. There are the correlations lower ones than that calculated for temperatures that can be treated significant in just one case, i.e. for the long-term precipitation factor (Fig. 2).

The strength of correlation with latitude turns out to be the highest when the exponential regression is applied and the curves are drawn on its basis ( Fig. 3). The highest values of $R^2$ were obtained for the average LITF from the three years of the study (Fig. 3).

The calculations and the analyses shown above clearly indicate that the changes in production of LITF depend first of all upon the thermal conditions within the pine forest sites along the N-S transect. The southward warming increases production of litter, and the pattern of this variability may be well described both by the exponential curve and by the straight line.

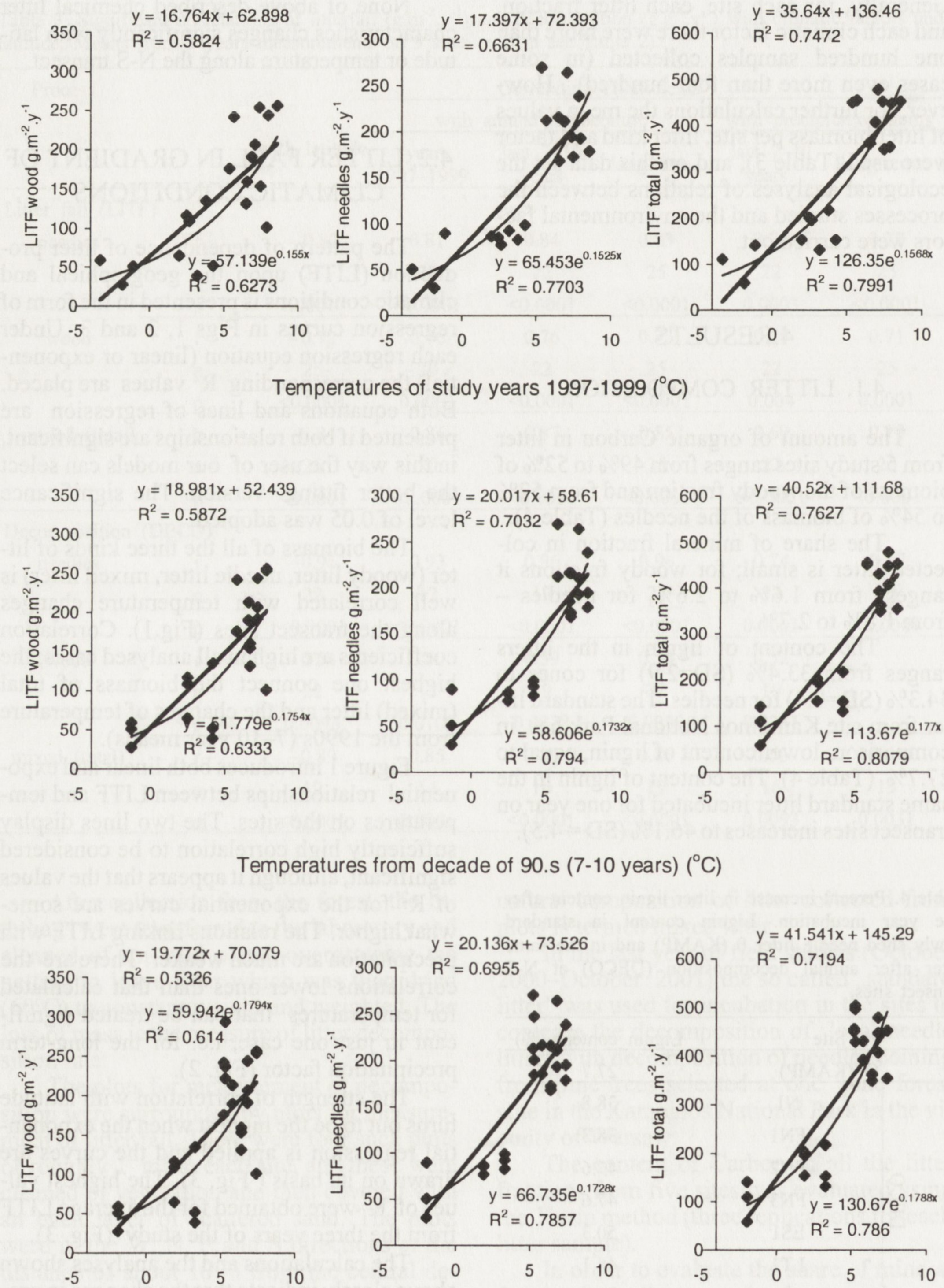



Fig. 1. Annual total litter fall (LITF) and two litter fractions (needle and wood) in relation to mean annual temperatures (°C) at study sites. Exponential and linear approximation.

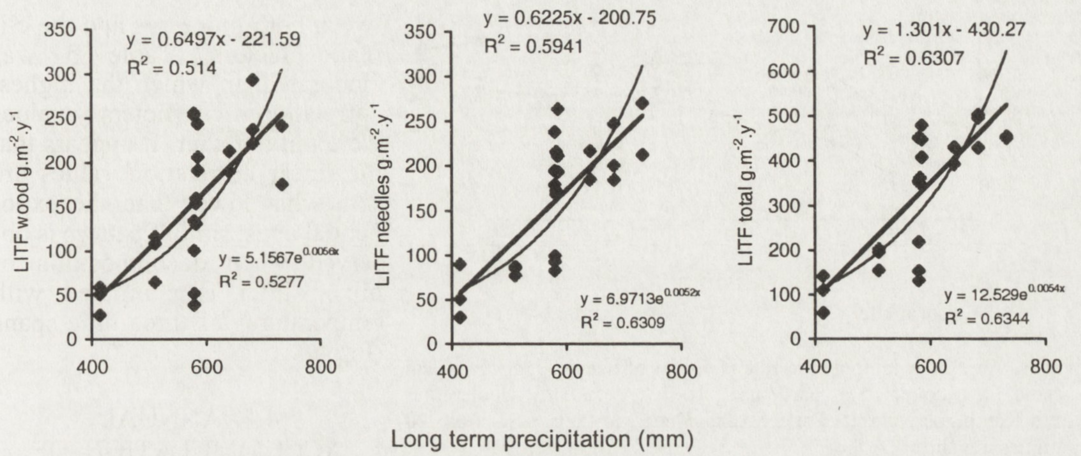



Fig. 2. Annual total litter fall (LITF) and two litter fractions (needle and wood) in relation to long-term annual precipitation sums (mm). Explanations as on Fig 1.

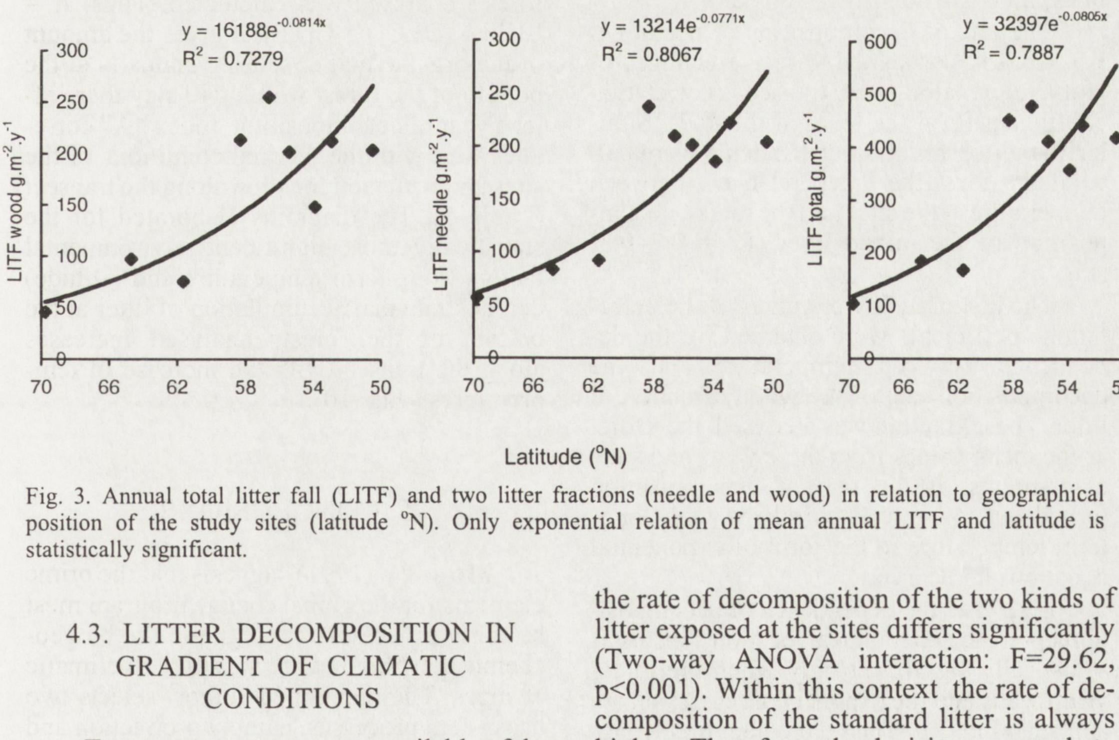



Fig. 3. Annual total litter fall (LITF) and two litter fractions (needle and wood) in relation to geographical position of the study sites (latitude °N). Only exponential relation of mean annual LITF and latitude is statistically significant.

## 4.3. LITTER DECOMPOSITION IN GRADIENT OF CLIMATIC CONDITIONS

Two measurements were available of the rate of litter decomposition (DECO) along the transect sites. The first one was based on the local litter, collected on the same site during the preceding year, and the second, based upon the so-called standard litter, identical for all the study sites, which was acquired from the pine forest in Kampinos National Park (515 litter bags with weighted standard needle portions were laid out for the year long incubation and then gathered). The course of the decomposition process of the two kinds of litter is shown in Fig. 4. It was concluded that the rate of decomposition of the two kinds of litter exposed at the sites differs significantly (Two-way ANOVA interaction: $F=29.62$, $p<0.001$). Within this context the rate of decomposition of the standard litter is always higher. Therefore, the decision was made to rely on the estimations of the rates of decomposition of local litter. All of the statistical analyses presented below are based uniquely on the local litters, which are certainly reflecting better the actual interactions in the organic matter production-decomposition processes taking place in the forests analysed.

Similarly as in the analysis of production of litter (LITF), also when analysing the rate of its decomposition (DECO) along the transect, the regression equations were used. The respective correlation coefficients and equa-

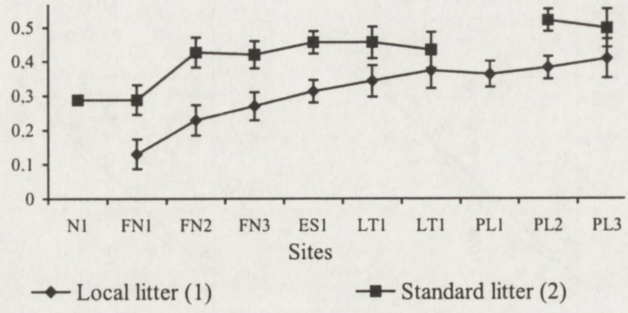



Fig. 4. Annual decomposition rate (DECO) of needle litter: 1 – local needle litter collected at particular sites, 2 – standard needle litter from Kampinos National Park. Mean values and their ± SD from 20 samples are shown.

tions, as well as the formulae and patterns representing the interdependencies obtained on this basis (the exponential and straight lines) are shown in Figs 5, 6, 7 and 8.

The rate of decomposition of needles is very clearly associated with the changes of temperature along the transect (correlation coefficient $R^2$ at the level of 0.8–0.9). Similarly high corrrelation coefficients were calculated for the dependence between temperature at the sites and the rate of decomposition of the mixed litter ($R^2$ = 0.7–0.8) (Fig. 6).

The distinctly lower values of the correlation coefficients were obtained for the dependence between temperature and the decomposition rate of the woody fraction of litter. These fraction was analysed, therefore, as the mean values from three years and such assessments of the rate of decomposition turned out to be well correlated with long-term temperature in the form of exponential equations and curves.

Likewise, the dependence of decomposition upon the geographical location appears as statistically significant only when the three-year means and the exponential regression are applied (Fig. 7). Then we obtain highly significant correlations for all the litter fractions.

Precipitation turns out to be the factor, which very rarely shapes the rate of decomposition of litter on the study transect, solely the decomposition of the needles and the mixed litter being associated with the long-term precipitation levels (Fig. 8). At the same time, significant correlation coefficients were observed for the long-term temperature and latitude.

In order to summarise the comparison of the linear and exponential interrelations between both processes and the climatic factors, Table 5 was elaborated, in which the highest correlation coefficient values were put together. It appears that the linear correlation values are somewhat lower than the exponential ones; similar pattern is observed when decomposition of mixed litter is compared with temperatures of three time spans (Fig. 9).

## 4.4. ANNUAL ACCUMMULATION OF ORGANIC MATTER

A simple indicator of accummulation (A) of the organic matter at the bottom of the forests analysed was calculated. Thus, A = LITF – (DECO × LITF). It gives the amount of the organic matter settling annually at the bottom of the forest which will stay there after a year of decomposition. Index "A" correlates well with the thermal conditions of the sites and with their location along the transect (Table 5). The diagrams elaborated for the statistically most significant environmental factors (long-term temperature and latitude) demonstrate that accumulation of litter at the bottom of the forests analysed increases along the transect with the increase of temperatures ( Fig. 10).

## 5. CONCLUSIONS

Mooney (1991) suggests that the prime elements for the global change program must be those processes that regulate the biogeochemical cycles and are sensitive to climatic changes. The mentioned author selects two ecosystem processes, namely production and decomposition of organic matter, as the essential regulators of the rates of flow of minerals and gases within the biosphere.

The same two ecosystem processes were considered as a part of this large and comprehensive project of studies of temperate and boreal pine forests on the transect crossing the European continent along the meridians 23–29°E (Breymeyer 2003, this volume).

Summing up the analyses described in this paper the following general findings concerning the behaviour of OM production and

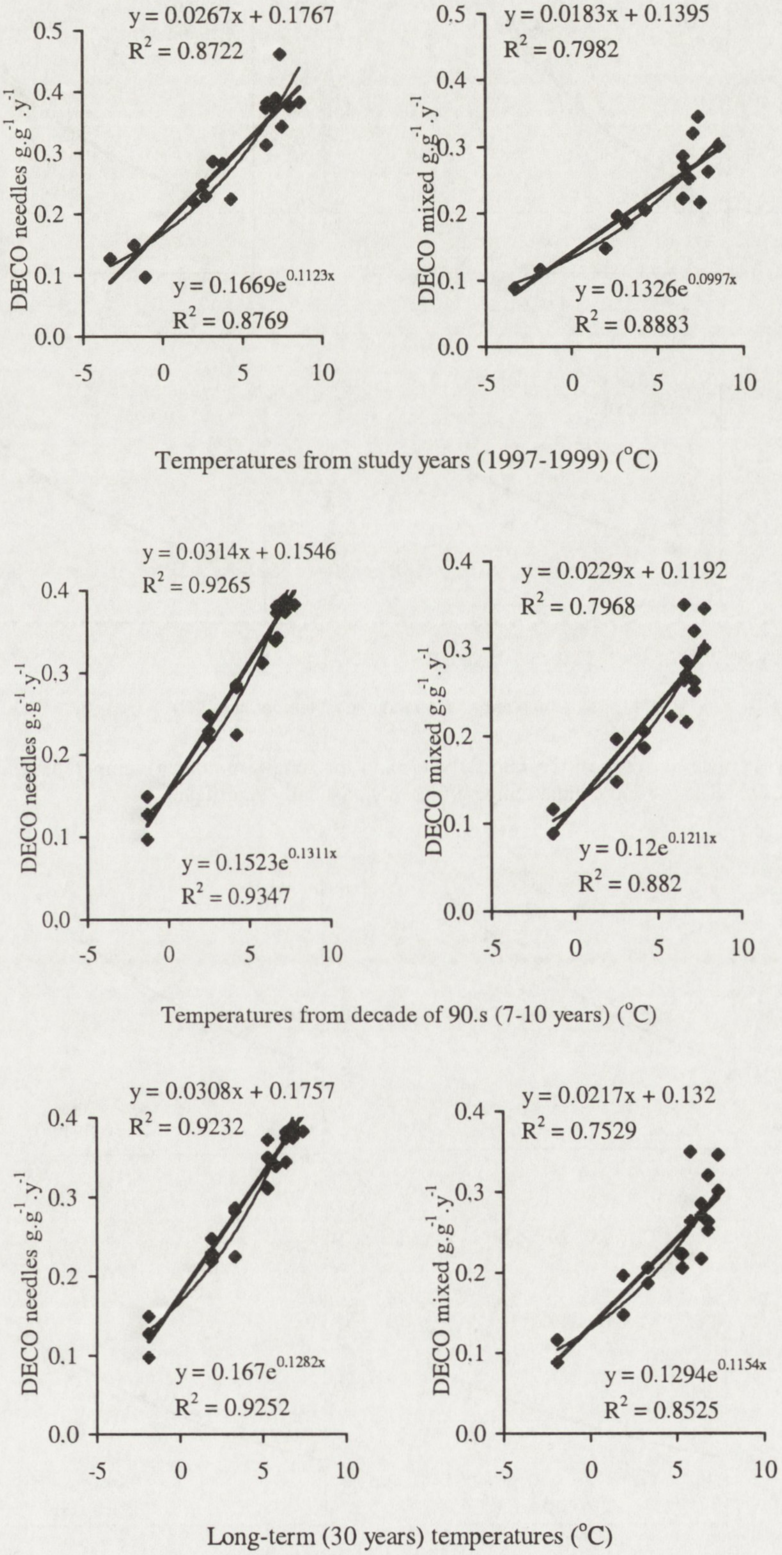



Fig. 5. Annual decomposition (DECO) rate of needle and mixed litter in relation to mean annual temperature (°C) at the sites. Explanations as on Fig. 1.

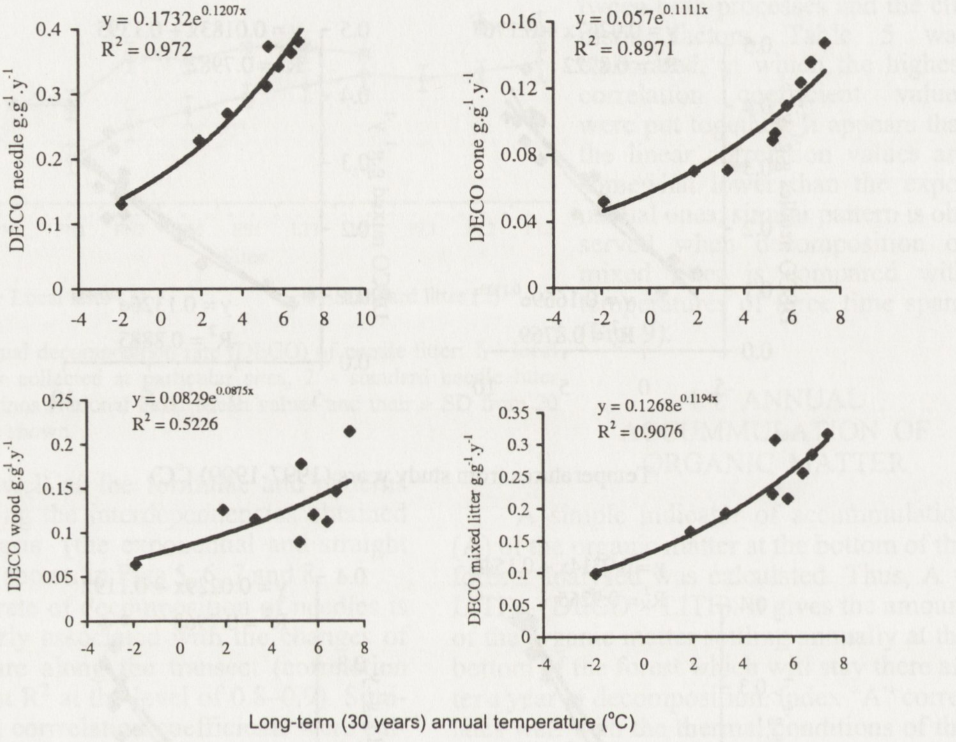



Fig. 6. Three-year mean decomposition rate (DECO) and the long-term annual temperature. Only exponential relation of DECO and long-term annual temperatures is statistically significant.

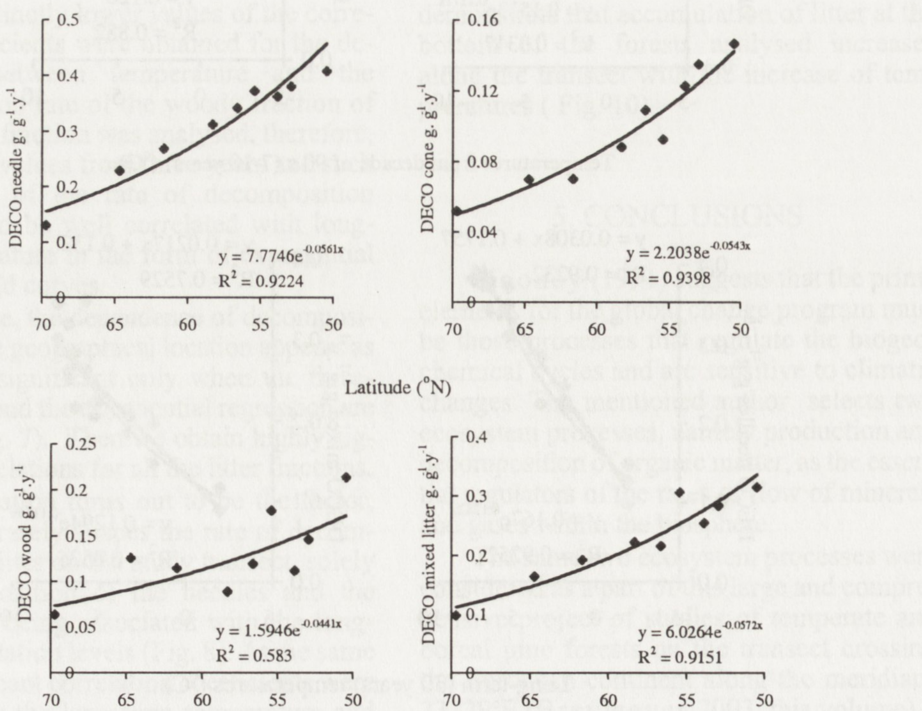



Fig. 7. Changes in decomposition rate (DECO) of all litter fractions with latitude. The mean rates from three-year periods are used.

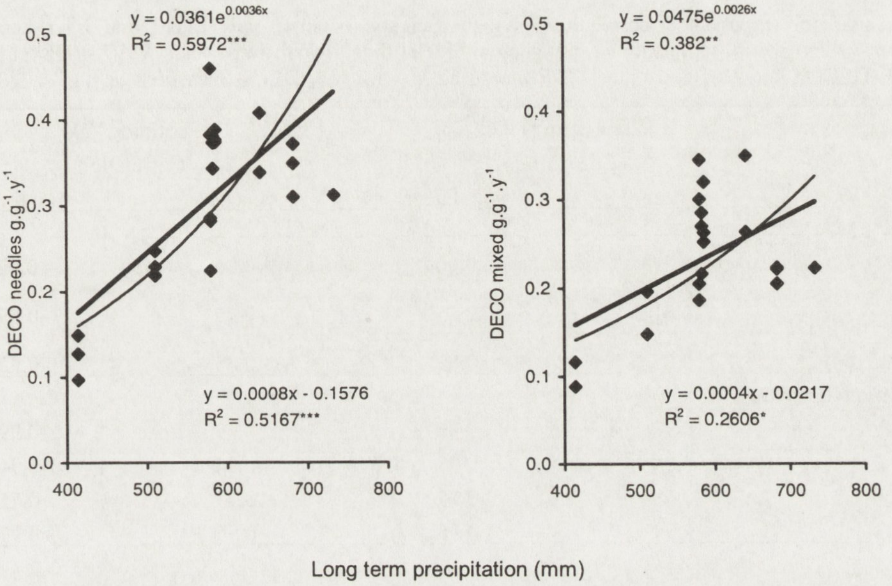
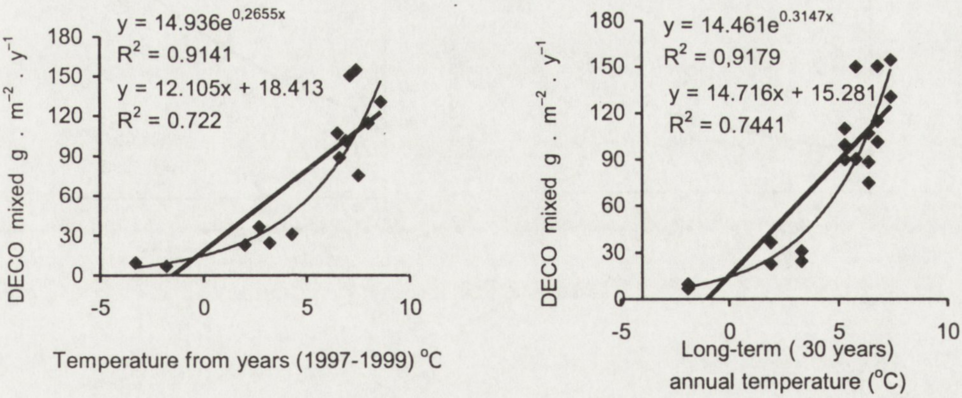



Fig. 8. Annual decomposition rates of needle and mixed litter in relation to long-term precipitation on the sites. Only long-term precipitation is correlated with DECO rates. Exponential relation shows stronger statistical significance, linear relation is weaker.



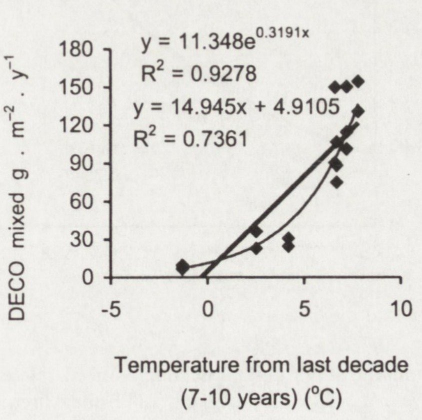




Fig. 9. Annual means of decayed mixed (total) litter in relation to temperatures on sites. The exponential curves show very high correlation power ($R^2$ above 0.9) of relations DECO – temperatures.

Table 5. Linear and exponential correlation ($R^2$) coefficients for litter fall (LITF) and litter decomposed (DECO) *versus* long-term temperature and geographic latitude. Data from years 1997–1998 (LITF) and 1997–1999 (DECO), for 9 transect sites LITF measured in g.m$^{-2}$.y$^{-1}$, DECO measured in g.g$^{-1}$.y$^{-1}$.

| Process | Long-term T °C Correlation | | Latitude °N Correlation | |
|---|---|---|---|---|
| | linear | non linear | linear | non linear |
| Litter fall (LITF) | | | | |
| needles | 0.87 | 0.90 | –0.86 | –0.92 |
| wood (cones + twigs) | 0.81 | 0.85 | –0.79 | –0.89 |
| total (mixed) | 0.86 | 0.89 | –0.85 | –0.92 |
| Decomposition (DECO) | | | | |
| needles | 0.97 | 0.96 | –0.99 | –0.99 |
| cones | 0.88 | 0.97 | –0.94 | –0.94 |
| twigs | 0.68 | 0.75 | –0.73 | –0.75 |
| mixed (total) | 0.94 | 0.96 | –0.95 | –0.97 |

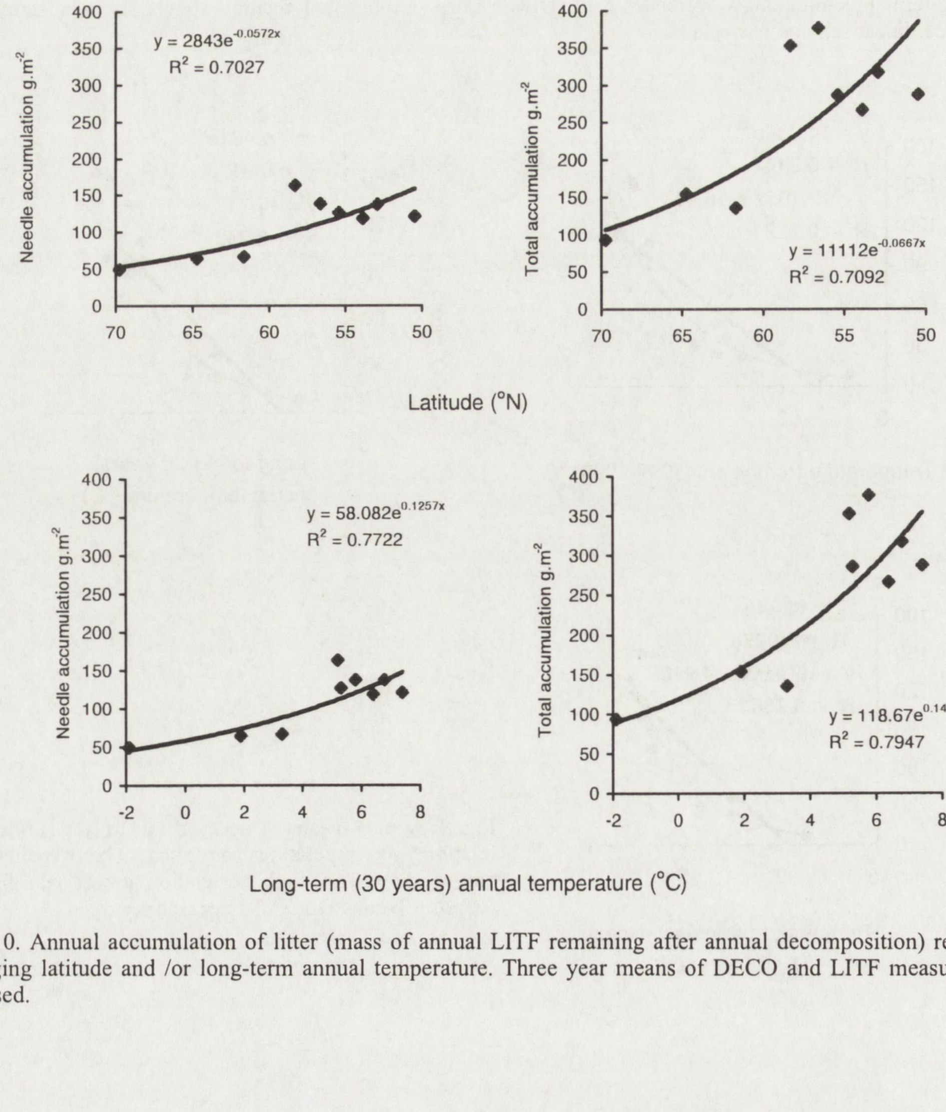



Fig. 10. Annual accumulation of litter (mass of annual LITF remaining after annual decomposition) related to changing latitude and /or long-term annual temperature. Three year means of DECO and LITF measurements are used.

Table 6. Annual accumulation of organic matter in forest bottom (1997–1999 average values); only significant correlations with climatic factors and latitude are introduced ($p<0.05$)

| Parameter measured | | Correlation coefficients | | | | | |
|---|---|---|---|---|---|---|---|
| | | with mean annual precipitation sum | | with mean annual temperature | | | with latitude |
| | | 7–10 years | long-term | years 1997–1999 | 7–10 years | long-term | |
| Needles accumulation (g.m$^{-2}$) | r | 0.64 | 0.76 | 0.81 | 0.82 | 0.80 | –0.8104 |
| | n | 19 | 22 | 17 | 19 | 22 | 22 |
| | p | 0.0034 | <0.0001 | 0.0001 | <0.0001 | <0.0001 | <0.0001 |
| Wood accumulation (g.m$^{-2}$) | r | 0.58 | 0.76 | 0.83 | | 0.78 | –0.80 |
| | n | 19 | 22 | 17 | | 22 | 22 |
| | p | 0.0087 | <0.0001 | <0.0001 | | <0.0001 | <0.0001 |
| Total accumulation (g.m$^{-2}$) | r | 0.63 | 0.81 | 0.89 | 0.45 | 0.81 | –0.8271 |
| | n | 19 | 22 | 17 | 22 | 22 | 22 |
| | p | 0.0038 | <0.0001 | <0.0001 | 0.0346 | <0.0001 | <0.0001 |

For explanation r, n, p see Table 2.

decomposition along the N-S transect can be formulated:

• the ecosystems of pine forests, situated along the N-S transect, change their pattern of functioning with the southward movement, that is with the increase of air temperature. The basic ecosystem processes of litter production (LITF) and decomposition (DECO) are stimulated by warming,

• the two processes considered (LITF and DECO) are most strongly associated with the long-term temperatures characteristic for the forest sites along the transect, although in several cases thermal conditions observed over shorter time periods (even over just two years of study) turn also out to be significant,

• the dependence of both kinds of processes upon precipitation is clearly less pronounced,

• of the various litter fractions analysed the needles react most spectacularly, while the woody fractions much less. The mixed litter, that is, the natural composition of LITF reacts very distinctly to the change of air temperature,

• the calculated annual accumulation of litter on particular study sites increases with increase of air temperature.

It appears that one should indicate also the shortcomings of studies conducted and the results obtained. In my opinion they include:

• the single annual measurements of both processes. With respect to DECO it is known that decomposition of litter is the quickest in the first period of its incubation, i.e. in the first year, after which the decomposition processes slow down. There are, however, reports suggesting that the commonly used so-called "first year decomposition" indicator can be treated as a good basis for comparisons of the OM output in an ecosystems (Berg and Ekbohm, 1991). In turn, with respect to LITF, collection of litter on the study plots just once a year causes that the litter samples are not homogeneous, containing namely also partly decomposed dead parts of plants. However, it is a natural situation and we are always faced with a definite degree of mixing of the plant fragments residing at the forest bottom for the different periods of time,

• the OM balance that we ultimately calculate as the OM accumulation, is obviously only partial and does not consider the whole above ground production and decomposition in upper soil layers. Yet, the distinct climatic conditioning of this "little LITF – DECO budget" certainly shapes the OM production-destruction processes within the entire pine forest ecosystem.

Linder *et al.* (1996), when introducing the IGBP-GCTE (International Geosphere-Biosphere Program-Global Change Terrestrial Ecosystems) plan for forest studies, propose as the first point "*Study sites and transects ... of representative range of forest types growing under different conditions ... with series of baseline observations ... and measurements of physiological processes*", to further indicate that "*The emphasis on process-level understanding acknowledges the lack of fundamental understanding about forest ecosystem carbon budgets ...*". These authors suggest temperate and boreal coniferous and mixed forests in northern Europe as forest of socio-economic importance, while Koch *et al.* (1995) lay out the plans of coordination of the potential network of transects studied within the IGBP/GCTE.

The above references associated with IGBP shows that the studies presented in this report fit appropriately the currently considered problem domain related to global change.

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