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Leaf and twig litter decomposition of main species in different forests along the north slope of Changbai Mountain, northeast China

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Abstract From 2001 to 2003, the litter decomposition dynamics of dominant tree species were conducted using a litterbag burying method in the broadleaf-Korean pine forest, spruce–fir forest and Ermans birch forest, which represents three altitudinal belts in Changbai Mountain, northeast China. The spatial and temporal dynamics of litter decomposition and the effects of litter properties were examined. Furthermore, the decomposition trend of different species was simulated by the Olson model, and results showed that annual mass loss rates increased over time, but was not significantly correlated. Leaf decomposition rates increased after decomposing for 638 days (1.75 years), and the order of dry weight remaining rates of leaf litter for different species is: Asian white birch (*Betula platyphylla*) (24.56%) < Amur linden (*Tilia amurensis*) (24.81%) < Korean pine (*Pinus koraiensis*) (38.48%) < spruce (*Picea jezoensis* var. *microsperma*) (41.15%) < Ermans birch (*Betula ermanii*) (41.53%) < fir (*Abies nephrolepis*) (42.62%). The dry weight remaining rates of twig litter was smaller than that of leaf litter, and followed the order of Amur linden (44.98%) < fir (64.62%) < Korean pine (72.07%) < spruce (73.51%) < Asian white birch (77.37%) < Ermans birch (80.35%). The simulation results by the Olson model showed that, in leaf, the 95%-decomposition rates ranged from 4.5 to 8.0 years, and annual decomposition rate (k) followed the order of Amur linden

(0.686) > Asian white birch (0.624) > Korean pine (0.441) > spruce (0.406) > fir (0.397) > Ermans birch (0.385); in twig, it ranged from 7.8 to 29.3 years, and k follows the order: Amur linden (0.391) > fir (0.204) > Korean pine (0.176) > spruce (0.157) > Asian white birch (0.148) > Ermans birch (0.102). In general, the differences of decomposition rate are evident between leaf and twig litter and among species, and were higher in broad-leaved species compared with coniferous species at the same elevation, and decreased with the ascending of elevation.

Keywords litter, decomposition, Changbai Mountain

1 Introduction

Litter decomposition is one of the key processes in nutrient cycling and an important link in the biology geochemical cycle within forest ecosystems (Swift et al., 1979), such as keeping soil fertility, supplying plants nutrient for their regrowth and accelerating substance cycling and nutrient balance in forest ecosystems. It is also an energy source and material of soil animals and microbes. Researches suggested that the release of nutrient elements from litter decomposition could afford annually 69%–87% energy for forest growth (Waring and Schlesinger, 1985). The difference of forest litter decomposition rate, to a large extent, could influence the forest productivity and biomass accumulation (Huang et al., 1998; Adrien, 2001).

The functions of litter in forest nutrient cycling have been studied early in 1876 (Ebermayer, 1876) and more investigations on litter decomposition in various forests were reported but most focused on leaf litter (Huang et al., 1998). The effects of abiotic environment and litter's substrate properties on litter decomposition were studied (Pauli, 1964; Harrison et al., 1971; Schaefer et al., 1985; Moorhead, 1989; Reid, 1991; Hornsby et al., 1995; Ma et al., 1997; Huang et al., 1998; Liu et al., 2000; Wang, 2002; Cheng, 2003; O'Neill et al., 2003; Rong, 2004; Qi, 2004; Wang et al., 2004). However, very few studies have been conducted simultaneously

Translated from *Acta Ecologica Sinica*, 2006, 26(4): 1,037–1,046 [译自: 生态学报]

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on the leaf and twig litter of different species within the same forest ecosystem and among different forest types at different elevations in the same climatic zone.

Three typical forests distributed at different altitudinal gradients on the north slope of Changbai Mountain were selected in this study area (namely, broadleaf-Korean pine forest, spruce–fir forest, and Ermans birch forest). The objectives of this study are to examine: 1) the differences of decomposition rate between leaf and twig, 2) the variations of decomposition rate among different species, and 3) the effects of abiotic environment on litter decomposition.

2 Study site and methods

2.1 Site description

Changbai Mountain is a famous mid-latitude mountain with primary forests without disturbance located in Jilin Province (41°42'45"–42°45'18" N, 127°33'30"–128°16'48" E) in northeast China. The mean annual temperature is 4.9–7.3°C and average annual rainfall is 600–900 mm. The study sites lie on the north slope of Changbai Mountain with broadleaf-Korean pine forest, spruce–fir forest, Ermans birch forest and other different forest types at different elevations along the north slope with different microclimates. Details of climatic condition in each site are listed in Table 1.

In broadleaf-Korean pine forest, dominant tree species include *Pinus koraiensis*, *Tilia amurensis*, *Acer mono*, *Fraxinus mandshurica*, *Tilia mandshurica*, and *Betula costata*; stand canopy density is 0.8; dominant shrub species include *Corylus mandshurica*, and *Philadelphus schrenkii*; main herbs include *Brachybotrys paridiformis*, *Cimicifuga simplex*, *Phryma leptostachya*, *Impatiens nolitangere*; soil type is dark brown forest soil.

Spruce–fir forest belongs to the dark coniferous forest of middle mountain, *Picea jezoensis*, *Abies nephrolepis*, *Larix olgensis* are dominant tree species with canopy density over 0.9; shrubs include *Acer ukurunduense*, *Lonicera edulis*, *Evonymus pauciflorus* etc.; herb species include *Maianthemum bifolium*, *Carex callitrichos*, *Solidago virga-aurea* var. *dahurica*, *Linnaea borealis* etc.; soil type is dark brown coniferous forest soil.

In Ermans birch forest, dominant tree species is *Betula ermanii*, mixed with few *Larix olgensis* and *Sorbus amurensis*, stand canopy density is 0.7; shrub species include *Lonicera edulis*, *Rhododendron chrysanthum*, *Vaccinium uliginosum*,

Phyllodoce caerulea etc. Herbs include *Cacalia auriculata*, *Sanguisorba tenuifolia*, etc.; soil type is mountainous soddy forest soil.

2.2 Materials and methods

Experiments began in October 2001. The leaf and twig litter (twigs about 1 cm in diameter) of the dominant tree species were collected respectively in three forests. The leaf and twig litter of *Tilia amurensis*, *Betula platyphylla* and *Pinus koraiensis* in broadleaf-Korean pine forest, those of *Abies nephrolepis* and *Picea jezoensis* in spruce–fir forest and *Betula ermanii* in birch forest were chosen for study. Leaf litter existing on fallen twigs was collected because leaf litter of *Abies nephrolepis* and *Picea jezoensis* is very difficult to be distinguished apart on the ground within the forest.

Litterbag burying method was chosen to examine the litter decomposition in the field. First, the collected litter was oven dried at 60°C for 24 h, and then 10 g of leaf litter or 20 g of twig litter was put into each of 36 nylon mesh bags (15 cm × 15 cm) with mesh size of 1 mm. Finally, all these bags were put in the field in three groups with 12 bags respectively for decomposition. After 2 months two bags of litter were collected and brought to the laboratory, and their chemical components and dry weight were determined after oven drying at 80°C for 24 h.

Two litterbags were collected from each group at the end of May, June and September in 2002 and 2003, brought to the laboratory, and washed carefully with clean water until free of mud and sand. Thereafter, dry weight was obtained after oven-drying at 80°C, and ground for further biochemical analyses, such as total nitrogen, phosphorus, potassium, carbon and lignin content.

3 Results

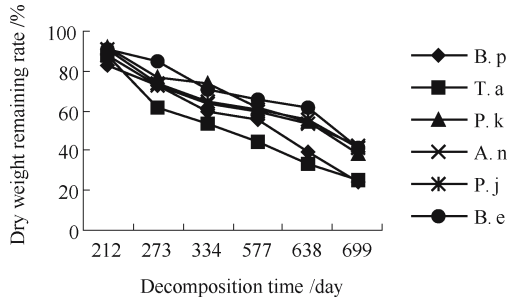
3.1 Dynamic process of litter decomposition of different tree species

Figure 1 shows that the dry weight remaining rates varied dramatically among different species. Dry weight loss of leaf litter of *Betula platyphylla* and *Tilia amurensis* are higher than that of other species. It is obvious that leaf decomposition rate of broad-leaved tree species was higher than that of coniferous tree under the same conditions within the same community.

Table 1 Climatic index along altitudinal gradient in the north slope of Changbai mountain

Forest type	Altitude /m	Mean annual temperature /°C	Annual average rainfall /mm	Rainfall from June to September /mm	Dryness index	Wetness index	Average temperature in January /°C	Average temperature in July /°C	Snow day /day
BLKP	740	2.52	688.96	489.97	0.65	2.03	−17.52	19.29	133.51
SF	1350	−0.50	854.81	607.93	0.46	3.89	−19.37	16.01	174.92
EB	1996	−3.33	1074.04	763.83	0.33	5.86	−21.10	12.92	218.77

Note: BLKP is broadleaf-Korean pine forest; SF is spruce–fir forest; EB is Ermans birch forest (Revised from Hao et al., 2002)



B.p (*Betula platyphylla*); T.a (*Tilia amurensis*); P.k (*Pinus koraiensis*); A.n (*Abies nephrolepis*); P.j (*Picea jezoensis* var. *microsperma*); B.e (*Betula ermanii*).

Fig. 1 Dynamic process of dry weight remaining rate of leaf litter decomposition

The dry weight remaining rate of leaf litter took on descending order over time, and the final dry weight remaining rate is: *Betula platyphylla* 24.56%, *Tilia amurensis* 24.81%, *Pinus koraiensis* 38.48%, *Picea jezoensis* var. *microsperma* 41.15%, *Betula ermanii* 41.53% and *Abies nephrolepis* 42.62%. At the same time, leaf litter decomposition rate became lower as elevation increased.

Twig decomposition rate was lower than that of leaf for each species on the whole (Fig. 2). Dry mass of twig litter for six species in three communities dropped greatly at the end of our experiment (699 days, 1.92 years). The final decomposition rates of twig litter of different tree species were close except that *Tilia amurensis* was much lower. Dry weight remaining rate followed the increasing order of *Tilia amurensis* (44.98%), *Abies nephrolepis* (64.62%), *Pinus koraiensis* (72.07%), *Picea jezoensis* var. *microsperma* (73.51%), *Betula platyphylla* (77.37%) and *Betula ermanii* (80.35%). The results showed that the impact of tree species on decomposition rate was more important than altitudinal change.

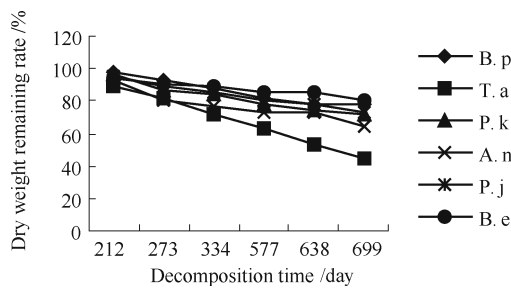


Fig. 2 Dynamic process of dry weight remaining rate of twig litter decomposition

3.2 Dynamic process of litter decomposition rate over time

Larger differences in the weight loss of litter existed in different seasons (Figs. 3 and 4). In winter (after 212 days), the weight loss rate of *Tilia amurensis* is lower than that of *Betula platyphylla*.

Although *Tilia amurensis* and *Betula platyphylla* both belong to broad-leaved tree species and grow in the same environment, the decomposition of *Betula platyphylla* leaves

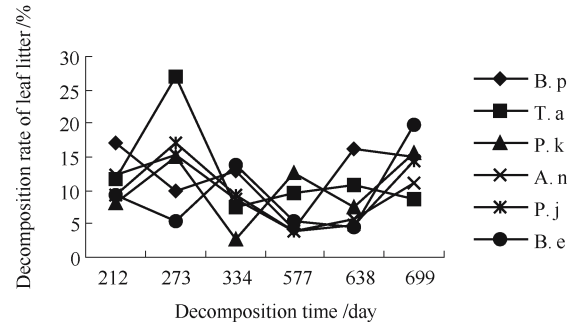


Fig. 3 Leaf litter decomposition rate over time (%)

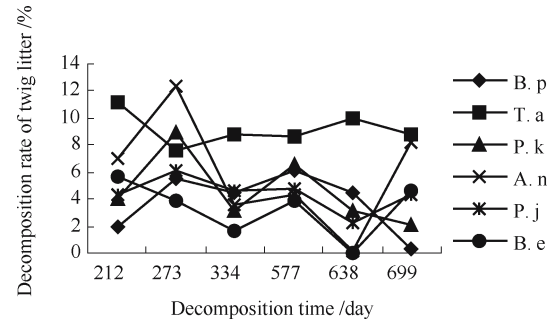


Fig. 4 Twig litter decomposition rate over time (%)

was faster and dry weight was almost the lowest after decomposing for 699 days, which might be due to the difference of original substrate properties.

The leaf litter decomposition of *Tilia amurensis*, *Pinus koraiensis*, *Abies nephrolepis* and *Picea jezoensis* in the 212–273rd day (May to July in the second year) became faster. The reasons are likely because of more rainfall retained, and higher relative humidity and temperature in this period (Table 1). The leaf litter of *Betula ermanii* in the 273–334th day (July to September in the second year) was faster, which might be correlated to the high height (1,996 m) and low temperature. It is noteworthy that the decomposition rate of the leaf litter of *Abies nephrolepis* and *Picea jezoensis* were faster than that of *Pinus koraiensis* in the 334th day, and also after that. The leaf decomposition rate of the six tree species increases obviously after 638 days.

Similarly, twig litter decomposition rate varied at different times and among species (Fig. 4). The decomposition rate of twig litter of *Tilia amurensis* ranked the highest in the 212nd day (at October to May in the second year) and kept a higher decomposition rate than others in the whole experimental period. Dry weight was lost mostly until after 699 days, which indicated that substrate properties might be the main influencing factor considering the same environment for *Betula platyphylla* and *Tilia amurensis*. The twig weight loss rates of *Betula platyphylla*, *Pinus koraiensis*, *Abies nephrolepis* and *Picea jezoensis* became faster in the next year (212–273 days later), in which the rainfall was higher with high relative humidity and temperature (Table 1). *Betula ermanii* leaves decomposed quickly after 212 days (at May in first year) compared with other species (*Abies nephrolepis*, *Picea jezoensis* and *Betula ermanii*).

3.3 Simulation of decomposition rates of different tree species

Litter decomposition is a complicated dynamic process. In order to figure out the variation of different trees' leaf weight lost during litter decomposition, the Olson model (Olson et al., 1963) was used to simulate the decomposition dynamics as follows:

$$X/X_0 = e^{-kt} \quad (1)$$

where t is the time (year), X_0 is the original weight of the litter, X is the remaining weight of the litter at time t and k is the rotten coefficient or decomposition coefficient (g/(g·year)).

Modeling results of litter decomposition of leaf and twig for different species are listed in Table 2. According to the Olson model, we developed an exponential regression equation of litter decomposition remaining over time. At the same time, we use this model to calculate the time of half-decomposition and 95%-decomposition (Table 2).

The variation range of the decomposition coefficient of the six species is from 0.385 to 0.686 among species (Table 2). The leaf decomposition rate of *Tilia amurensis* is the highest, with the time of half-decomposition of 1.136 years and 95%-decomposition of 4.494 years; followed by *Betula platyphylla*, with the time of half-decomposition of 1.281 years and 95%-decomposition of 4.970 years; and *Betula ermanii*, with the time of half-decomposition of 1.985 years and 95%-decomposition of 7.961 years.

Table 3 indicates that the annual variation range of twig litter decomposition coefficient of the six tree species is between 0.102 and 0.391. Twig litter decomposition rate of *Tilia amurensis* is faster than that of others, and the time of half-decomposition is 1.920 years and 95%-decomposition of 7.806 years. Ranked second is *Abies nephrolepis* twig with a time of half-decomposition of 3.325 years and 95%-decomposition of 14.590 years. *Betula ermanii* twig is in the last place with half-decomposition of 6.723 years and 95%-decomposition of 29.342 years.

In general, the time of 95%-decomposition of twig litter is 7.8–29.3 years and the variations for different tree species are

marked in different vertical vegetation distribution belts on the north slope of Changbai Mountain.

3.4 Effects of litter properties on decomposition dynamics

We find that the relationship between decomposition rate and initial chemical component content varied slightly among different components (R^2 is between 0.01 and 0.60). It indicates that there was unremarkable correlation between the decomposition of all kinds of leaf litter and twig litter and initial chemical component content.

We compared substrate properties and decomposition rates of chemical component contents of all kinds of leaf litter and twig litter (Table 4). It was found that the nutrient contents of leaf are higher than that of twig. The N content of leaf is about 2.13-fold, the P content is 1.22-fold, and the K content is 2.9-fold higher than that of twig. Some nutrients of litter are necessary for decomposers and may influence decomposer's activities. The higher the initial nutrient content (especially N), the stronger the microbe's activities and the higher the decomposition rate. The organic matters decompose slowly if C:N and lignin:N are high. Litter decomposition rates will be reduced when N content is relatively low because microbial growth is restricted and organic matter decompose slowly.

4 Discussion

We find that the decomposition rate of broad-leaved tree litter was higher than that of coniferous tree. In the early stage, leaf litter decomposition rates reached maximum value and slowed down later. Decomposition rate increased after 1.75 years. Decomposition rate of twig litter was much lower than that of leaf litter. Litter decomposition rates declined with the increase of elevation. The shortest time of 95%-decomposition of leaf litter appeared in *Tilia mandshurica* (4.494 years), and the longest in *Betula ermanii* (7.961 years). The shortest of 95%-decomposition of twig litter was found in *Tilia mandshurica* (7.806 years), and the longest in *Betula costata* (29.342 years). Decomposition rates varied because

Table 2 Modeling results of the litter decomposition rate for different species

Species	Equation	Correlation efficiency (R^2)	Decomposition rate	Time of half-decomposition /year	Time of 95%-decomposition /year
B.p	$y = 111.24e^{-0.624,2x}$	0.844	0.624	1.281	4.970
B.p	$y = 102.61e^{-0.148,2x}$	0.952	0.148	4.851	20.388
T.a	$y = 108.98e^{-0.685,7x}$	0.923	0.686	1.136	4.494
T.a	$y = 105.97e^{-0.391,2x}$	0.937	0.391	1.920	7.806
P.k	$y = 108.97e^{-0.441,4x}$	0.886	0.441	1.765	6.982
P.k	$y = 101.13e^{-0.175,9x}$	0.960	0.176	4.004	17.095
A.n	$y = 101.01e^{-0.396,6x}$	0.913	0.397	1.773	7.579
A.n	$y = 98.66e^{-0.204,4x}$	0.898	0.204	3.325	14.590
P.j	$y = 103.09e^{-0.405,7x}$	0.885	0.406	1.784	7.459
P.j	$y = 101.09e^{-0.156,7x}$	0.959	0.157	4.493	19.187
B.e	$y = 107.41e^{-0.385,3x}$	0.835	0.385	1.985	7.961
B.e	$y = 99.129e^{-0.101,8x}$	0.953	0.102	6.723	29.342

Table 3 Initial chemical component concentration and decomposition rate of leaf litter

Average	N /%	P /%	K /%	C:N	C:P	Lignin:N	<i>k</i>	Time of 95%-decomposition /year
Leaf	1.28	0.25	0.33	42.70	219.70	21.08	0.49	6.57
Twig	0.60	0.20	0.11	86.91	242.49	44.13	0.20	18.07
Leaf:Twig	2.13	1.22	2.90	0.49	0.91	0.48	2.49	0.36

of different litter properties and environment. The annual mass loss rates of litter gradually descended with the rise of elevation. The annual litter mass loss rates of six species ranged from 10% to 20% for leaf and from 30% to 40% for twig.

The time of 95%-decomposition of leaf litter varied between 4.5 and 8.0 years. The result is consistent with that of Chen (2004) who found that the time of 95%-decomposition is 4.1 years and 11.5 years, respectively, for Juglas and larch forest. The temperature and humidity in the broadleaf-Korean pine forest are more suitable for decomposers than in the *Betula ermanii* forest, and twig litter of *Tilia amurensis* is easily used by decomposers because its C:N, C:P and lignin:N values are the lowest among all studied tree species (Table 4). The lowest decomposition rate occurred in *Betula ermanii* owing to the more disadvantageous environment for its decomposition.

The Olson model was applied to analyze the litter decomposition coefficient in some studies in China (Table 4). Decomposition rates varied because of the difference in properties and environment of litter at different climate zones. The litter's decomposition coefficient reduced as elevation increased (Table 4). In the same climate zones, the *k* of a broad-leaved tree is bigger than that of a coniferous tree. Many studies reported were based on the mixture of twigs and leaves because it is difficult to compare their decomposition separately. Due to the high elevation of Changbai Mountain, decomposition coefficient of litter is small, and the time of half-decomposition and 95%-decomposition is long.

The research frontiers about litter rates mostly concentrated on measuring the communities' litter mass loss rates. Chen et al. (1982) studied the litter of the *Pteridium aquilinum* grass ecosystem in Hampsfell of England. The mass loss rate for 10 months was 22%. This was the early report about litter decomposition rate in China (Liu Dongxia, 2004), and more studies are listed in Table 5.

The annual biomass loss rates of twig litter were clearly lower than that of leaf litter and decreased as elevation increased. The annual litter biomass loss rate of broad-leaved trees is higher than that of coniferous trees, and broad-leaved forests in the temperate zone is lower than that in the subtropical zone, which indicates that there is a close relationship between litter decomposition and elevation. In our experiment, the annual biomass loss rates of six species change between 10% and 20% in leaf litter, and between 25% and 40% in twig litter.

Litter decomposition was influenced by both environment and litter properties, such as the nutrient content and physical and chemical structure of litter components. It is inaccurate

to estimate litter decomposition rate without analyzing the whole process of litter decomposition, because the loss rates of all kinds of inorganic and organic components during litter decomposition are not consistent. Many scholars consider that N, a macroelement in litter, can make litter decomposition easier because it is easily dissolved and utilized by plants. Some conclude that lignin is the representation of litter physical and chemical properties because it plays a dominant role in controlling litter decomposition rate. Austin et al. (2000) referred that C:N is an essential property of litter. Melillo et al. (1982) considered that there was a tight relationship between lignin:N and decomposition rate or *k*. Austin et al. (2000) found the negative correlation between decomposition and lignin during the litter decomposition for some tree species in primary forests in Hawaii. Salamanca et al. (1998) thought that lignin or lignin:N determined decomposition rates in the late stage. The indices, such as lignin:N and C:N, are considered to reflect the rate of litter decomposition. We found that there are no prominent relationships between decomposition rates of leaf litter and twig litter of different tree species and their initial chemical component contents, but if all species are integrated into leaf and twig litter, there is a prominent correlation.

In this study, the leaf litter decomposition rates of *Abies nephrolepis* and *Pinus koraiensis* were higher than that of *Pinus koraiensis* at the beginning of 334 days. But the initial N content of leaf litter of *Abies nephrolepis* and *Picea jezoensis* var. *microsperma* was lower than that of *Pinus koraiensis*'s, and their C:N was higher than *Pinus koraiensis*'s. They are located in an elevation higher than *Pinus koraiensis*, which might be the reason of combined influences of litter substrate properties and altitudinal factor (Mo, 2004). Therefore, the difference on specific leaf area between broad-leaved and coniferous species is the primary reason that makes the decomposition rates different. We also found that the decomposition rate of *Abies nephrolepis* twigs was lower than that of *Tilia mandshurica*, and the decomposition rate of *Betula costata* twigs was relatively higher than that of *Betula ermanii*. The mechanism is still unclear, which needs to be investigated further. It is obvious that litter decomposition rates were influenced by various factors, and the complex process and theory still need systematic discussion.

Therefore, the difference of the water and heat condition resulted from the elevation difference will control litter decomposition rates by influencing microorganism activities. Berg (1993) concluded that the decomposition of litter went through two phases of changes controlled by nutrition and fiber respectively. In the first phase, the decomposition rate of litter is fast, but slow in the second phase. For example, in

Table 4 Litter decomposition rates of different forest communities

Climate zone	Forest type	Site	Decomposition rate	Time of half-decomposition /year	Time of 95%-decomposition /year	References	Remark
Cold temperate belt	Broadleaf-Korean pine forest	North slope of Changbai mountain	0.584	1.4	5.5	This study	Leaf
Cold temperate belt	Spruce-fir forest	North slope of Changbai mountain	0.400	1.8	7.5	This study	Leaf
Cold temperate belt	Subalpine <i>Betula ermanii</i> forest	North slope of Changbai mountain	0.385	2.0	8.0	This study	Leaf
Cold temperate belt	Broadleaf-Korean pine forest	North slope of Changbai mountain	0.240	3.6	15.1	This study	Twig
Cold temperate belt	Spruce-fir forest	North slope of Changbai mountain	0.181	3.9	16.9	This study	Twig
Cold temperate belt	Subalpine <i>Betula ermanii</i> forest	North slope of Changbai mountain	0.100	6.7	29.3	This study	Twig
Cold temperate belt	Pure <i>Juglans mandshurica</i>	Maoershan mountain, Heilongjiang	0.375	0.5	4.1	Chen et al., 2004	Leaf
Cold temperate belt	Pure <i>Larix gmelinii</i>	Maoershan mountain, Heilongjiang	0.130	1.5	11.5	Chen et al., 2004	Leaf
Cold temperate belt	Mixed forest of <i>Juglans mandshurica</i> and <i>Larix gmelinii</i>	Maoershan mountain, Heilongjiang	0.235	0.8	6.2	Chen et al., 2004	Leaf
Subtropics	30-year subalpine <i>Picea</i> plantation	Western Sichuan	0.280	2.5		Lin et al., 2003	
Subtropics	40-year subalpine <i>Picea</i> plantation	Western Sichuan	0.260	2.7		Lin et al., 2003	
Subtropics	Subalpine second <i>Picea</i> forest	Western Sichuan	0.460	1.5		Lin et al., 2003	
Subtropics	Subalpine original <i>Picea</i> forest	Western Sichuan	0.395	1.8		Lin et al., 2003	
Subtropics	18-year <i>Cunninghamia lanceolata</i> forest	Tianlinlaoshan, Guangxi	0.33			Liang et al., 1993	Leaf
Subtropics	18-year <i>Cunninghamia lanceolata</i> forest	Tianlinlaoshan, Guangxi	0.206			Liang et al., 1993	Twig
Subtropics	18-year <i>Cunninghamia lanceolata</i> forest	Tianlinlaoshan, Guangxi	0.240			Liang et al., 1993	Fruit
Subtropics	24–28-year <i>Cunninghamia lanceolata</i> forest	Longshengliu, Guangxi	0.499			Wen et al., 1990	Leaf
Subtropics	24–28-year <i>Cunninghamia lanceolata</i> forest	Longshengliu, Guangxi	0.420			Wen et al., 1990	Twig
Subtropics	24–28-year <i>Cunninghamia lanceolata</i> forest	Longshengliu, Guangxi	0.417			Wen et al., 1990	Fruit
Subtropics	8-year <i>Cunninghamia lanceolata</i> forest	Youxi, Fujian	0.520			Ma et al., 1997	Leaf
Subtropics	8-year <i>Cunninghamia lanceolata</i> forest	Youxi, Fujian	0.275			Ma et al., 1997	Twig
Subtropics	8-year <i>Cunninghamia lanceolata</i> forest	Youxi, Fujian	0.340			Ma et al., 1997	Fruit
Subtropics	<i>Taxodium ascendens</i> forest	Yanan innig area, Guangdong	1.071			Zhou et al., 2003	
Subtropics	<i>Cryptocarya concinna</i> community	Dinghushan mountain	1.070			Yi et al., 1994	
Subtropics	Original <i>Picea</i> forest	Miyaluo forest area, Li County, Sichuan	0.460	2.5	10.85	Pang et al., 2004	
Subtropics	The second <i>Betula</i> forest	Miyaluo forest area, Li County, Sichuan	0.390	2.7	11.5	Pang et al., 2004	
Subtropics	30-year <i>Picea</i> plantation	Miyaluo forest area, Li County, Sichuan	0.280	1.5	6.5	Pang et al., 2004	
Subtropics	40-year <i>Picea</i> plantation	Miyaluo forest area, Li County, Sichuan	0.260	1.8	7.6	Pang et al., 2004	
Subtropics	27-year <i>Cunninghamia lanceolata</i> forest	Sanming, Fujian	0.769	0.9	3.9	He et al., 2003	Leaf
Subtropics	27-year <i>Cunninghamia lanceolata</i> forest	Sanming, Fujian	0.250	2.8	1.7	He et al., 2003	Twig
Subtropics	25-year <i>Cunninghamia lanceolata</i> forest	Nanning, Fujian	1.475			Lin et al., 2001	Twig
Subtropics	Broad-leaved evergreen forest	Tiantong, Zhejiang	0.558–6.280	1–4		Wang, 2004	Leaf
Subtropics	Broad-leaved evergreen forest	Tiantong, Zhejiang			3.7	Zhang et al., 1999	
Tropics	Mountain rain forest	Jianfengling mountain, Hainan	0.836–1.597			Lu et al., 1994	
Tropics	Semi-deciduous seasonal rain forest	Jianfengling mountain, Hainan	1.578–2.172			Lu et al., 1994	

Table 5 The annual mass loss rates of litters of varied forest communities

Climate zone	Forest type	Site	Annual mass loss rate /%	References	Remark
Cold temperate zone	Broadleaf-Korean pine forest	North slope of Changbai mountain	38.48	This paper	Leaf
Cold temperate zone	Spruce-fir forest	North slope of Changbai mountain	31.67	This paper	Leaf
Cold temperate zone	Ermans Birch forest	North slope of Changbai mountain	26.93	This paper	Leaf
Cold temperate zone	Broadleaf-Korean pine forest	North slope of Changbai mountain	18.35	This paper	Twig
Cold temperate zone	Spruce-fir forest	North slope of Changbai mountain	16.58	This paper	Twig
Cold temperate zone	Ermans birch forest	North slope of Changbai mountain	10.47	This paper	Twig
Temperate zone	<i>Pinus tabulaeformis</i> plantation and <i>Quercus variabilis</i> forest	West mountain of Beijing	21.84	Hu et al., 1986	
Cold temperate zone	Pure <i>Juglans mandshurica</i> forest	Maoershan mountain, Heilongjiang	61.5	Chun et al., 2004	
Cold temperate zone	Mixed <i>Juglans mandshurica</i> and <i>Larix variabilis</i> forest	Maoershan mountain, Heilongjiang	40.9	Chun et al., 2004	
Cold temperate zone	Pure larch forest	Maoershan mountain, Heilongjiang	24.7	Chun et al., 2004	
Subtropical zone	Subalpine spruce plantation	Western Sichuan	24.35	Lin et al., 2003	
Subtropical zone	Subalpine spruce plantation 40 years old	Western Sichuan	22.87	Lin et al., 2003	
Subtropical zone	Subalpine secondary spruce forest	Western Sichuan	36.96	Lin et al., 2003	
Subtropical zone	Subalpine primary spruce forest	Western Sichuan	32.23	Lin et al., 2003	
Subtropical zone	<i>Pinus massoniana</i> forest	Guangxi	33.03	Liang et al., 1991	
Subtropical zone	<i>Cunninghamia lanceolata</i> young forest	Longxi, Fujian	39.73	Ma et al., 1997	
Subtropical zone	<i>Taxodium ascendens</i> forest	Yanan innig area, Guangdong	57.48	Zhou, 2003	
Subtropical zone	19-year-old <i>Cunninghamia lanceolata</i> forest	Tianlinlaoshan mountain	44.5	Liang et al., 1993	
Subtropical zone	<i>Cryptocarya concinna</i> community	Dinghushan mountain	70.2	Yi et al., 1994	
Subtropical zone	27-year-old <i>Cunninghamia lanceolata</i> forest	Sanming, Fujian	53.66	He et al., 2003	Leaf
Subtropical zone	27-year-old <i>Cunninghamia lanceolata</i> forest	Sanming, Fujian	22.13	He et al., 2003	Twig

pine needle-leaf litter the initial N content was less than 1.15%, the first phase lasts less than 2 years, and the initial N content was 1.22%, lasting for 5 years (Mo et al., 2004). In our study, the initial N content of coniferous trees was 1.255%–1.548%, and the decomposition rate of the three species of coniferous trees increased on 699 days (1.92 years). For the three species of broad-leaved trees, because of shortage of data, we just supposed that decomposition would get along with the fluctuating phase, but this hypothesis still needs more studies.

It can be concluded that the differences of decomposition rate are evident between leaf litter and twig litter and among species with different litter properties. They were also higher for broad-leaved species compared to coniferous species at the same elevation, and decreased with the increase of elevation.

Acknowledgements This study was partly supported by the National Natural Science Foundation of China (Grant No. 30240084), the Knowledge Innovation Program of the Chinese Academy of Sciences (CAS) “(CXOG-E01-02 and KZCX1-SW-01)”. The authors also thank Mr. Dai Guanhua and other staffs from Changbai mountain Forest Ecosystem Research Station of the Chinese Academy of Sciences for their support in the field sampling.

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