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The growth process of natural poplar-birch forests

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Abstract With a combination of permanent and temporary sample plots, we investigated the growth conditions of natural poplar-birch forests. The forests were divided into four site classes, using statistical and analytical techniques in a quantitative model, in descending order where site class I was the best. On this basis, the growth of natural poplar-birch forests in the different site classes was studied. The growth processes of height and diameter at breast height were divided into three stages: a fast growing period, a stable growing period and a slow growing period. Results of this study provide a theoretical basis for the directive cultivation of natural poplar-birch forests.

Keywords natural poplar-birch forests, site classification, growth process

1 Introduction

The poplar-birch forest is a general designation for pure trembling aspen, pure birch and mixed stands of both species. In the secondary forest of the Heilongjiang Province 36.43% of the area and 31.77% of the volume cumulation are poplar-birch forests. Most of the existing poplar-birch forests are immature timber in the period of rapid growth. The quality of the timber is good and this timber is fit for

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vener panels, pulpwood and building purposes. In this paper, we present the growth of the natural poplar-birch forest based on site classification (Zhong, 1990; Luan et al., 1999) and we explain the effect of different management intensities on the utility rate of luminous energy, litter decomposing and the growth of poplar-birch forests. These have important theoretical and practical consequences for raising forest productivity and for increasing yield per unit area.

2 Study areas and methods

2.1 Site description

The research was carried out at the Xiaoxing'anling Mountains, Wanda Mountains and Zhangguangcai Mountains Forest Bureau (Farm), which are located in the eastern part of the Heilongjiang Province. The area is located between latitude 44°50'–47°40'N and longitude 127°10'–130°30'E, at elevations between 600 m and 1,000 m. The days of effective temperature equal or more than 10°C in the entire year are 100–110 days and the average annual temperature is –2–2°C. The average annual rainfall is 550–680 mm, with 70% in July and August. Average annual relative humidity is 64%–71% and annual average evaporation 1,000–1,220 mm. The soil type is mostly mountain dark brown soil, which developed from parent material of granite and basalt.

2.2 Study methods

We combined two methods—observation of permanent sample plots and investigation of temporary sample plots and set up 420 temporary standard field blocks each with an area of 1,000 m² and fixed standard field blocks in both trembling aspen and birch forests with densities of 0.5, 0.6, 0.7, 0.8 and 1.0. In each temporary standard block, 3 trees were chosen for analytic tree analysis. A total of 1,260 trees were surveyed as well as general measurements made and site factors recorded. In the fixed standard field blocks, the growth of forest and decomposition of litter were deter-

mined as well as the utility rates of luminous energy for four years.

Photosynthesis was measured during the most favorable period of tree growth under different weather conditions by the modified half-leaf method. The methods of measuring photosynthesis and the utility rate of luminous energy are as follows:

Net photosynthetic intensity = (dry weight of leave after irradiation – dry weight of leave before irradiation) / (total area of sample leave × hours of irradiation);

Utility rate of luminous energy (%) = (photosynthetic intensity × 2.55 / (intercepted radiant energy from surface of leave)) × 100.

In each standard field block, we established five sample areas of 40 cm × 50 cm and litter was collected in the handmade wire netting of the same size as the sample area. We then spread the litter on the woodland for later air-drying and weighing. After one year, the litter was taken out, air-dried and weighted again. The difference in the weights was the annual decomposition from which we obtained the amount of nutrients in the litter, and then we calculated the amount of nutrient return.

3 Result and analysis

3.1 Site classification of poplar-birch forests

Site factor is an important ecological condition for forest

growth. We classified the site factors based on data from field investigations and used exposure, gradient, location in the hillside and the thickness of humus layer as independent variables and site index as the dependent variable. We used a quantitative method and selected the absolute value of the partial correlation coefficients in descending order to identify site classes I (the best), II, III and IV. The results are shown in Table 1.

Table 1 shows that for trembling aspen, the conditions for site class I were as follows: partial sunny exposure, middle part of the hillside, gradient 6–15°, thickness of humus layer ≥ 31 cm; the conditions of site class II were full shade, top of the hillside, gradient 16–25°, thickness of humus layer 21–30 cm; the conditions of site class III were exposure to the sun, bottom of the hill, gradient 0–5°, thickness of humus layer 11–20 cm and site class IV was characterized by partial shade, ridge of the hillside, gradient ≥ 26° and thickness of humus layer ≤ 10 cm. For birch, site class I conditions were partial shade, bottom of the hill, gradient 6–15°, thickness of humus layer ≥ 31 cm; site class II conditions were partial sunny exposure, middle part of the hillside, gradient 0–5°, thickness of humus layer 21–30 cm; the conditions for site class III were full shade, top of the hill, gradient 16–25°, thickness of humus layer 11–20 cm and site class IV prevailed under the conditions of sunny exposure, ridge of the hillside, gradient ≥ 26° and thickness of humus layer ≤ 10 cm.

Table 1 Site classification of natural trembling aspen and birch forests

Item	Sort	Trembling aspen		Birch	
		Partial correlation coefficient	Site class	Partial correlation coefficient	Site class
Exposure	Sun	0.005,46	III	-0.005,05	IV
	Partial sun	-0.049,52	I	0.007,43	II
	Shade	0.036,36	II	0.007,23	III
	Partial shade	-0.002,52	IV	0.007,45	I
Location	Ridge	0.001,34	IV	-0.001,65	IV
	Top	0.007,71	II	-0.008,81	III
	Middle part	0.008,66	I	0.152,81	II
	Bottom	0.006,26	III	0.164,11	I
Gradient	0–5°	-0.092,84	III	-0.102,04	II
	6–15°	0.228,13	I	0.116,09	I
	16–25°	0.143,12	II	0.007,63	III
	≥26°	0.026,25	IV	0.001,69	IV
Thickness of humus layer	≤10 cm	0.039,89	IV	-0.011,22	IV
	11–20 cm	-0.144,58	III	0.013,42	III
	21–30 cm	-0.203,17	II	0.019,21	II
	≥31 cm	0.266,34	I	-0.025,86	I

3.2 Growth of natural poplar-birch forests by site class

Given the conditions described above, we classified this information in an ordinal manner for statistical analysis. We regressed average height (H_i) and diameter at breast height (DBH_i) of both species, for each site class ($i = 1, \dots, 4$), over time (A) at two year intervals and got the model (see Table 2). Then, we calculated the annual height and diameter increment (Tables 3 and 4) of the two forests under dif-

ferent site conditions during the growth period (Figs. 1–4).

From Tables 3 and 4 and Figs. 1–4, it is seen that growth of trembling aspen and birch forests for different site classes falls into three phases (Table 5): A is a period of fast growth (before age 20), B a period of stabilized growth (age 20–40) and C a period of slow growth (after 40 years). Taking the main cutting age as 50 years (Xu, 1994; Luan et al., 2000) for both forests during the three growth phases, we can see from Table 5 that:

Table 2 Model of H and DBH increment of trembling aspen and birch.

Forest	Regression equation		Sequence number
Birch	$DBH_1 = -1.790,0+0.919,3A-0.013,9A^2+0.000,10A^3$	$R=0.99$	1
	$DBH_2 = -1.456,7+0.696,6A-0.007,9A^2+0.000,04A^3$	$R=0.99$	2
	$DBH_3 = -2.046,7+0.685,2A-0.009,7A^2+0.000,07A^3$	$R=0.99$	3
	$DBH_4 = -1.913,3+0.533,3A-0.004,3A^2+0.000,000,3A^3$	$R=0.99$	4
	$H_1 = -1.063,3+1.031,5A-0.014,8A^2+0.000,08A^3$	$R=0.99$	5
	$H_2 = -0.732,0+0.828,2A-0.008,3A^2+0.000,01A^3$	$R=0.99$	6
	$H_3 = -1.087,0+0.777,9A-0.008,9A^2+0.000,03A^3$	$R=0.99$	7
	$H_4 = -1.146,0+0.765,3A-0.012,0A^2+0.000,07A^3$	$R=0.99$	8
Trembling aspen	$DBH_1 = -0.149,0+0.773,5A-0.009,4A^2+0.000,06A^3$	$R=0.99$	9
	$DBH_2 = -0.993,3+0.773,5A-0.009,7A^2+0.000,07A^3$	$R=0.99$	10
	$DBH_3 = -1.726,7+0.732,4A-0.009,3A^2+0.000,07A^3$	$R=0.99$	11
	$DBH_4 = -1.873,3+0.687,9A-0.003,6A^2+0.000,05A^3$	$R=0.99$	12
	$H_1 = -0.797,6+1.305,6A-0.012,9A^2+0.000,06A^3$	$R=0.99$	13
	$H_2 = -0.591,3+0.927,8A-0.011,2A^2+0.000,05A^3$	$R=0.99$	14
	$H_3 = -1.329,0+0.957,8A-0.010,8A^2+0.000,03A^3$	$R=0.99$	15
	$H_4 = -1.842,0+0.894,7A-0.010,2A^2+0.000,04A^3$	$R=0.99$	16

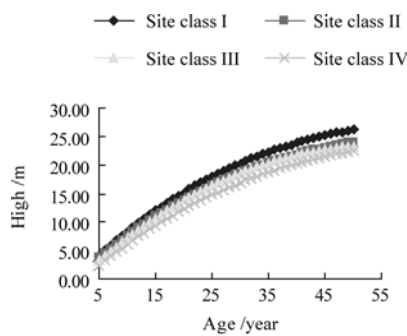


Fig. 1 H increment of trembling aspen for different site classes

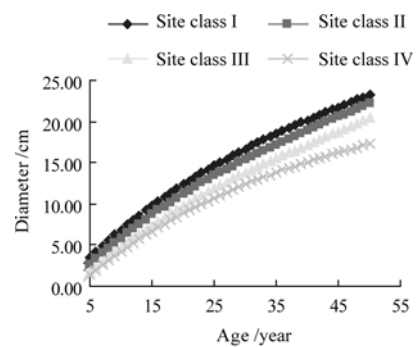


Fig. 2 DBH increment of trembling aspen for different site classes

Table 3 DBH and *H* increment of birch for different site classes

Age /year	Site class I			Site class II			Site class III			Site class IV						
	DBH /cm	DBH increment / (cm·year ⁻¹)	<i>H</i> /m	<i>H</i> increment / (m·year ⁻¹)	DBH /cm	DBH increment / (cm·year ⁻¹)	<i>H</i> /m	<i>H</i> increment / (m·year ⁻¹)	DBH /cm	DBH increment / (cm·year ⁻¹)	<i>H</i> /m	<i>H</i> increment / (m·year ⁻¹)				
4	1.67	0.42	2.83	0.71	1.21	0.31	2.45	0.64	0.54	0.14	1.83	0.46	0.15	0.04	1.72	0.50
6	3.25	0.79	4.61	0.89	2.45	0.62	3.94	0.75	1.73	0.60	3.21	0.69	1.13	0.49	3.03	0.66
8	4.73	0.74	6.28	0.84	3.63	0.59	5.37	0.72	2.85	0.56	4.52	0.66	2.08	0.48	4.24	0.61
10	6.11	0.69	7.85	0.79	4.76	0.55	6.73	0.68	3.90	0.53	5.77	0.63	2.99	0.46	5.38	0.57
12	7.41	0.65	9.32	0.74	5.83	0.54	8.03	0.65	4.90	0.50	6.96	0.60	3.87	0.44	6.43	0.53
14	8.63	0.61	10.70	0.64	6.86	0.52	9.26	0.62	5.84	0.47	8.08	0.56	4.72	0.43	7.41	0.49
16	9.77	0.55	11.98	0.64	7.83	0.49	10.44	0.59	6.72	0.44	9.14	0.53	5.53	0.41	8.31	0.45
18	10.84	0.54	13.18	0.60	8.76	0.47	11.54	0.55	7.55	0.42	10.15	0.51	6.31	0.39	9.15	0.42
20	11.84	0.50	14.29	0.56	9.64	0.44	12.59	0.53	8.34	0.40	11.09	0.47	7.06	0.38	9.92	0.39
22	12.77	0.47	15.32	0.52	10.47	0.42	13.58	0.50	9.08	0.37	11.98	0.45	7.77	0.36	10.62	0.35
24	13.65	0.44	16.27	0.48	11.26	0.40	14.50	0.46	9.78	0.35	12.81	0.42	8.45	0.34	11.28	0.33
26	14.47	0.41	17.16	0.45	12.02	0.38	15.37	0.44	10.44	0.33	13.59	0.39	9.10	0.33	11.87	0.30
28	15.25	0.39	17.97	0.41	12.73	0.36	16.17	0.40	11.07	0.32	14.32	0.37	9.71	0.31	12.41	0.27
30	15.98	0.37	18.72	0.38	13.41	0.34	16.91	0.37	11.67	0.30	14.99	0.34	10.30	0.30	12.90	0.25
32	16.67	0.35	19.41	0.35	14.06	0.33	17.60	0.35	12.24	0.29	15.62	0.32	10.85	0.28	13.35	0.23
34	17.33	0.33	20.04	0.32	14.67	0.31	18.23	0.32	12.79	0.28	16.19	0.29	11.37	0.26	13.75	0.20
36	17.96	0.32	20.62	0.29	15.25	0.29	18.79	0.28	13.32	0.27	16.72	0.27	11.85	0.24	14.11	0.18
38	18.59	0.32	21.15	0.27	15.80	0.28	19.30	0.26	13.83	0.26	17.21	0.25	12.31	0.23	14.45	0.17
40	19.14	0.28	21.64	0.25	16.33	0.27	19.76	0.23	14.32	0.25	17.65	0.22	12.73	0.21	14.75	0.15
42	19.71	0.29	22.08	0.22	16.83	0.25	20.15	0.20	14.81	0.25	18.05	0.20	13.12	0.24	15.01	0.13
44	20.27	0.28	22.48	0.20	17.31	0.24	20.49	0.17	15.29	0.24	18.41	0.18	13.48	0.18	15.26	0.13
46	20.82	0.28	22.86	0.19	17.76	0.23	20.78	0.15	15.76	0.24	18.73	0.16	13.81	0.17	15.48	0.11
48	21.37	0.28	23.20	0.17	18.20	0.22	21.00	0.11	16.24	0.24	19.01	0.14	14.11	0.15	15.68	0.10
50	21.92	0.28	23.51	0.16	18.62	0.21	21.18	0.09	16.71	0.24	19.25	0.12	14.38	0.14	15.87	0.10

Table 4 DBH and *H* increment of trembling aspen for different site classes

Age /year	Site class I			Site class II			Site class III			Site class IV						
	DBH /cm	<i>H</i> /m	<i>H</i> increment /(m·year ⁻¹)	DBH /cm	<i>H</i> /m	<i>H</i> increment /(m·year ⁻¹)	DBH /cm	<i>H</i> /m	<i>H</i> increment /(m·year ⁻¹)	DBH /cm	<i>H</i> /m	<i>H</i> increment /(m·year ⁻¹)				
4	2.86	0.72	3.14	0.79	1.95	0.49	2.94	0.74	1.06	0.27	2.33	0.59	0.74	0.19	1.58	0.40
6	4.26	0.70	4.96	0.91	3.31	0.68	4.58	0.82	2.35	0.65	4.04	0.86	1.96	0.61	3.17	0.80
8	5.59	0.67	6.69	0.87	4.61	0.65	6.14	0.78	3.57	0.61	5.66	0.81	3.11	0.58	4.68	0.76
10	6.86	0.64	8.33	0.82	5.84	0.62	7.62	0.74	4.74	0.59	7.20	0.77	4.20	0.55	6.13	0.73
12	8.06	0.60	9.88	0.78	7.01	0.59	9.02	0.70	5.84	0.55	8.66	0.73	5.30	0.55	7.49	0.68
14	9.21	0.58	11.34	0.73	8.13	0.56	10.34	0.66	6.90	0.53	10.05	0.70	6.21	0.46	8.79	0.65
16	10.31	0.55	12.72	0.69	9.19	0.53	11.59	0.63	7.90	0.50	11.35	0.65	7.12	0.46	10.03	0.62
18	11.35	0.52	14.01	0.65	10.20	0.51	12.77	0.59	8.85	0.56	12.59	0.62	8.01	0.45	11.19	0.58
20	12.34	0.50	15.23	0.61	11.16	0.48	13.88	0.56	9.76	0.46	13.75	0.58	8.84	0.42	12.29	0.55
22	13.29	0.48	16.38	0.58	12.07	0.46	14.93	0.53	10.63	0.44	14.83	0.54	9.63	0.40	13.33	0.52
24	14.19	0.45	17.46	0.54	12.95	0.44	15.92	0.50	11.46	0.42	15.85	0.51	10.37	0.37	14.31	0.49
26	15.05	0.43	18.46	0.50	13.79	0.42	16.84	0.46	12.26	0.40	16.80	0.48	11.08	0.36	15.23	0.46
28	15.88	0.42	19.40	0.47	14.60	0.41	17.70	0.43	13.03	0.39	17.69	0.45	11.74	0.33	16.09	0.43
30	16.67	0.40	20.28	0.44	15.37	0.39	18.51	0.41	13.77	0.37	18.50	0.41	12.37	0.32	16.90	0.41
32	17.42	0.38	21.10	0.41	16.20	0.42	19.27	0.38	14.48	0.36	19.24	0.37	12.97	0.30	17.65	0.38
34	18.15	0.37	21.86	0.38	16.84	0.32	19.97	0.35	15.18	0.35	19.93	0.35	13.54	0.29	18.36	0.36
36	18.85	0.35	22.57	0.36	17.55	0.36	20.63	0.33	15.85	0.34	20.55	0.31	14.07	0.27	19.01	0.33
38	19.53	0.34	23.22	0.33	18.23	0.34	21.24	0.31	16.52	0.34	21.12	0.29	14.59	0.26	19.62	0.31
40	20.19	0.33	23.83	0.31	18.91	0.34	21.80	0.28	17.17	0.33	21.62	0.25	15.08	0.25	20.19	0.29
42	20.83	0.32	24.39	0.28	19.57	0.33	22.32	0.26	17.82	0.33	22.07	0.23	15.55	0.24	20.71	0.26
44	21.46	0.32	24.91	0.26	20.22	0.33	22.81	0.25	18.46	0.32	22.46	0.20	16.00	0.23	21.19	0.24
46	22.07	0.31	25.38	0.24	20.88	0.33	23.26	0.23	19.10	0.32	22.80	0.17	16.44	0.22	21.62	0.22
48	22.68	0.31	25.83	0.23	21.53	0.33	23.67	0.21	19.74	0.32	23.08	0.14	16.86	0.21	22.03	0.21
50	23.26	0.29	26.23	0.20	22.18	0.33	24.05	0.19	20.39	0.33	23.31	0.12	17.27	0.21	22.39	0.18

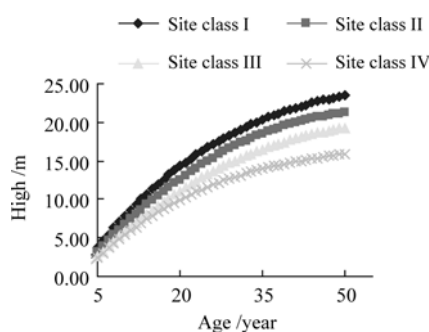


Fig. 3 H increment of birch for different site classes

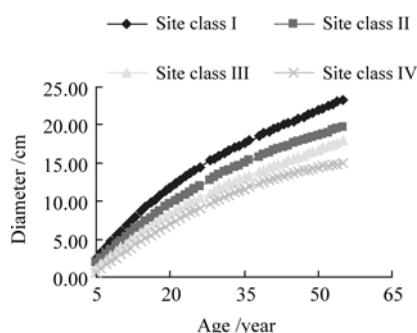


Fig. 4 DBH increment of birch for different site classes

a) For birch, the proportion of diameter increment during the entire growing period was 51%–54%, 34%–39% and 10%–13%; the amount of growth was 0.40–0.61 cm, 0.29–0.37 cm and 0.18–0.29 cm; the proportion of height increment during the entire growing period was 58%–63%, 31%–34% and 6%–8% and the amount of growth was 0.52–0.72 m, 0.24–0.37 m and 0.10–0.19 m in each of the three growth phases, respectively.

b) For trembling aspen, the proportion of diameter increment during the entire growing period was 48%–51%, 33%–40% and 7%–15%; the amount of growth was 0.48–0.61 cm, 0.32–0.40 cm and 0.23–0.33 cm; the proportion of height increment during the entire growing period was 55%–58%, 33%–36% and 7%–9% and the amount of growth was 0.65–0.77 m, 0.39–0.43 m and 0.14–0.25 m in each of the three periods, respectively.

These results show distinctly the differences in forest growth under the various site conditions, while the rates of height and diameter increment were rather similar as indicated by the correlations between forest growth and site conditions. Details are shown in Table 5.

Table 6 shows that, in the period of fast growth, the percentage growth of height and diameter of trembling aspen ranged from 54.89% to 60.47% and from 48.04% to 52.79%, respectively; during the period of stabilized growth these were 30.86%–35.24% and 33.90%–36.42% and during the period of slow growth 7.25%–9.87% and 12.72%–15.69%. For birch, the growth percentage of height and diameter

Table 5 Average DBH and H increment and their proportion of each growth phase during the entire period of birch and trembling aspen based on site classification

Forest	Growth phase	Site class I		Site class II		Site class III		Site class IV									
		DBH increment		H increment		DBH increment		H increment									
		Per. /%	Aver. /cm	Per. /%	Aver. /m	Per. /%	Aver. /cm	Per. /%	Aver. /m								
Birch	A	54	0.61	61	0.72	52	0.51	60	0.64	53	0.46	58	0.57	51	0.40	63	0.52
	B	34	0.37	32	0.37	36	0.34	34	0.36	34	0.31	34	0.33	39	0.29	31	0.24
	C	12	0.29	7	0.19	12	0.23	6	0.15	13	0.25	8	0.16	10	0.18	6	0.10
Trembling aspen	A	53	0.61	58	0.77	51	0.57	58	0.71	48	0.53	59	0.70	52	0.48	55	0.65
	B	40	0.40	33	0.43	35	0.38	33	0.40	37	0.37	34	0.39	37	0.32	36	0.39
	C	7	0.31	9	0.25	14	0.33	9	0.23	15	0.33	7	0.18	11	0.23	9	0.14

Table 6 Proportion of DBH and H increment of each growth phase during the entire period of birch and trembling aspen (%)

Forest	Period of fast growth		Period of stabilized growth		Period of slow growth	
	H	DBH	H	DBH	H	DBH
Trembling aspen	54.89	48.04	30.86	33.90	7.25	12.72
	60.47	52.79	35.24	36.42	9.87	15.69
Birch	52.25	49.70	30.37	33.33	6.95	10.71
	62.51	53.88	33.80	39.28	8.19	14.37

during the three growth periods were 52.25%–62.51% and 49.70%–53.88%, 30.37%–33.80% and 33.33%–39.28%, 6.95%–8.19% and 10.71%–14.37%, respectively.

3.3 The effect of density on the growth of poplar-birch forests

The existing stands of secondary poplar-birch forests are naturally regenerated and distributed asymmetrically, which result from that the seeds did not fall uniformly and artificial destruction (Cai, 1987). Therefore, both high and low density forests did not meet the standards of fully stocked stands and could not make full use of luminous energy with a subsequent lower per unit area yield and lower forest quality.

When the density of poplar-birch forests was too high, the efficiency of luminous energy use was high. However, many leaves overlapped and the leaves underneath breathed actively and consumed increasing amount of organic matter to compensate for the shortage of light for a long period of time. At the same time, the higher the forest density, the bigger its crown density and the radiant energy reaching the ground tailed off, which resulted in lower temperatures under the crown canopy and in the soil, which weakened the quantity and activity of soil microorganisms and affected the speed of litter decomposition. When the density of forests was too low, a great deal of light reached the ground through the interstices of leaves, light was wasted and its energy could not be fully utilized, which resulted in a decrease in the growth rate of poplar-birch forests.

In order to find the effect of density on the growth rate of poplar-birch forests we chose five trial sites of different densities: 0.5, 0.6, 0.7 and 0.8 and measured photosynthesis, litter decomposition, the amount of nutrients returned and

the amount of forest growth (Table 7).

From Table 7, we can clearly see that density had an effect on the efficiency of luminous energy use, accumulation of dry matter, efficiency of leaf decomposition and amounts of elements in return nutrient. Both efficiency of luminous energy use and the accumulated dry matter reached a maximum at a density of 0.7. Litter decomposition decreased with increasing density. The largest amounts of elements in return nutrient were at the middle densities; when the density was low, the amount of litter was also low and when the density was high the efficiency of decomposition decreased.

4 Conclusion

By means of a quantitative model, we divided the natural poplar-birch forests into four site classes, where site class I represented the best living conditions and, in decreasing order of site quality, site classes II, III and IV.

Based on this site classification of poplar-birch forests, we divided the growth of natural poplar-birch forests into three growth phases. These were a period of fast growth (before age 20), a period of stabilized growth (among 20–40) and a period of slow growth (after 40 years). In the fast growth phase, the proportion of average height and diameter growth over the entire growing period was 54.89%–60.47% and 48.04%–52.79% for trembling aspen and 52.25%–62.51% and 49.70%–53.88% for birch.

The efficiency of luminous energy use and accumulation of dry matter both reached their maximum at a density of 0.7. Decomposition of litter decreased when density increased. The largest amounts of elements in return nutrient were found at the middle densities.

Table 7 Relationship of density with use of luminous energy, litter decomposition and forest growth

Density	Average DBH /cm	Stem volume /($\text{m}^3 \cdot \text{hm}^{-2}$)	Accumulating of dry matter /($\text{kg} \cdot \text{hm}^{-2}$)	Efficiency of luminous energy use /%	Efficiency of decomposition /%	Amount of elements in nutrient returned /($\text{kg} \cdot \text{hm}^{-2}$)				
						N	P	K	Ca	Mg
0.5	12.94	3.386,1	1,474.47	1.45	50.88	130.76	11.12	19.21	59.30	13.53
0.6	11.91	3.566,2	1,707.45	1.51	47.89	133.50	11.35	19.61	60.54	13.81
0.7	12.45	4.021,8	2,147.12	1.68	46.36	136.48	11.60	20.05	61.89	14.12
0.8	12.05	3.019,9	1,866.76	1.46	37.29	117.15	9.96	17.21	53.13	12.12
CK	12.20				35.09	124.80	10.61	18.33	56.59	12.91

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