Postfire Recovery of Forest Litter in Scots Pine Forests in Two Different Regions of Boreal Zone

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Investigations carried out in the Kola peninsula (northern taiga) and in the South-western part of Western Siberia (southern taiga and forest-steppe) revealed identical course of the postfire restoration process of forest litter thickness in Scots pine forests. Despite the differences in mean annual temperature (2°C) and other climatic characteristics the recovery time for thickness of forest litter in both regions amounts to 90–100 years after fire in pine forests of lichen site type and 120–140 years – in green moss type; the thickness of forest litter therewith corresponds 3–4 cm and 7–8 cm respectively. That means that within the natural borders of pine forests, communities of a specific type possess uniform characteristics of restoration. On the basis of empirical data it appears that the predicted increase of mean annual temperature of earth surface by (2°C) will not bring changes into the character of postfire recovery of forest litter thickness. It was shown that during the period of the recovery, which spans about 90 years after fire in pine forests of lichen and green moss–lichen site types and 140 years in ones of green moss site types, the rate of increasing of carbon store in the forest litter averaged 0.6 t ha^{-1} $year^{-1}$, 0.1 t ha^{-1} $year^{-1}$ and 0.2 t ha^{-1} $year^{-1}$, respectively.

Keywords Scots pine forests, postfire recovery, forest litter
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1 Introduction

One of the probable impacts of the observed global increase of CO_2 concentration in the atmosphere is changes in climate. The question of what such a change will be like, and whether or not it will even occur, is much discussed nowadays (Clark 1982, Houphton et al. 1990, Anklin et al. 1993, Kondratjev 1993, Lorius and Oeschger 1994, Gorshkov 1995).

According to model-based calculations a twofold increase of the atmospheric carbon dioxide concentration will make the mean annual temperature of earth surface and mean annual temperature of earth surface in high latitudes rise up to 2–3°C and 7–9°C respectively (Clark et al. 1982, Klein 1982, Hoffton et al. 1990, Manabe et al. 1994).

Most modern papers concerning modelling and forecasting of possible changes in vegetation and soil due to predicted global warming (Peters 1990, Nazimova and Polykarpov 1995, Velichko and Morozova 1996) assume that there exists a direct relationship between average climate characteristics (average annual temperature, continental index) and biota.

The given research makes it possible to estimate the range of climate characteristics within which a forest community of a specific type would be stable. One of the main indicators of a community stability is their recovery after having been exposed to an external force. Recovery time of characteristics of various community components and their values in undisturbed communities are of fundamental nature.

Forest litter (forest floor, the upper part of the organic soil horizon excluding humus layer) – is one of the main components of boreal forest ecosystem. In the northern pine forests it contains 25–30 % of the total organic matter (alive and dead) and 10–20 % of organic carbon store in podzolic soils (Nikonov 1987, Alexeyev and Birdsey 1994).

This paper aims at investigation of the processes of forest litter postfire recovery in pine forests (*Pinus sylvestris* L.)* of two climatically different geographical regions.

2 Material and Methods

2.1 The Sites

The communities compared are situated in the north and the south of the natural area of pine (*Pinus sylvestris*) forests (Lavrenko and Sochava 1956) in the Kola peninsula (67–68°N, 30–34°E, northern taiga) and in the south-west of Western Siberia (55–59°N, 62–66°W, southern taiga and forest-steppe). Data on the Kola peninsula were obtained in this study, data on Western Siberia were taken from the work of S.N Sannikov and N.S Sannikova (1985). Climate characteristics of the regions of investigation are given in Table 1.

In the Kola peninsula Scots pine forests of three types were studied: lichen (a) – lichen share in moss–lichen cover exceeds 70 %, moss–lichen (b) – lichen share ranges from 30 % to 70 %, and green moss (c) – lichen share in moss–lichen cover is less than 30 %. The postfire period in the selected sites spans from 5 to 210 years.

In the south-western part of Western Siberia lichen (d) and green moss (e) site types of Scots pine forests with fire ages from 3 to 175 years were studied. Lichen site type was represented by communities "where lichens dominated in the ground cover", green moss site type was represented by ones "dominated by green moss" (Sannikov and Sannikova 1985).

The communities analyzed are situated on plains and hills formed by sandy and loam sandy deposits (glacial and glaciofluvial) in the Kola peninsula and alluvio-deluvial in the south-west of Western Siberia).

* Vascular plant nomenclature follows Cherepanov (1995); lichens follow Santesson (1993); mosses follow Ignatov, Afonina (1992)

Table 1. Geographical and climatic characteristics of regions compared[(1)].

Characteristics		Region: Kola peninsula	SW of W.Siberia
Site location	latitude, N	67°–68°	56°–59°
	longitude, E	31°–35°	62°–66°
Altitude, m		130–200	100–150
Temperature, °C	mean annual	–0.5..–1.0	1.0..1.5
	mean January	–12..–14	–16..–18
	mean July	13..14	18..19
Duration of frost-free period, days		75–104	105–121
Quantity of days	with $t \geq 5°C$	120–122	164–168
	with $t \geq 10°C$	58–60	120–132
Precipitation, mm	450	550	
Potential evaporation, mm		250	600

(1) on data derived from Scientific and applied reference book on the climate of the USSR (1987, 1988, 1989, 1990).

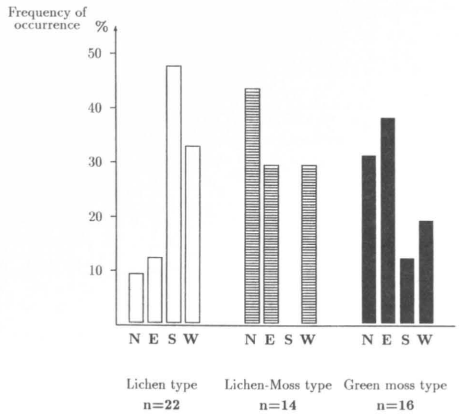

Fig. 1. Occurrence of Scots pine forests on slopes of differing aspects in the Kola peninsula. 1.Lichen site type (share of lichens in moss–lichen cover exeedes 70 %). 2.Green moss–lichen site type (share of lichens in moss–lichen cover 30–70 %). 3.Green moss site type (share of lichens in moss–lichen cover is under 30 %).

Table 2. Soil properties of regions compared (on data derived from Menshikova 1990, Nikonov 1987; Nadezhdin 1960; Sannikov 1992).

Region	Soil layer	Density, g/cm³	Clay, % (1)	pH (KCl) (2)	C, % (3)	N, % (4)	Ca mequiv./100 g (5)	Mg
Lichen site type of forest								
Kola	A0	0.12	–	3.0–3.2	25–40	0.5–0.6	3.3–16.0	3.6–14.8
penin-	A2	1.4–1.5	3–4	3.2–3.4	0.2–1.2	<0.1–0.1	0.1–0.8	0.2–0.7
sula	B_1	1.5–1.7	4–5	4.0–5.2	0.5–2.9	<0.1–0.1	0.4–0.5	0.1–0.4
SW of	A0	nd	–	4.6–5.3	nd	nd	nd	nd
Western	A_1A_2	nd	3–7	4.5–4.6	1.3	<0.1–0.1	2–3#	
Siberia	B_1	nd	3–7	4.5–5.3	0.5	<0.1–0.1	2–3#	
Green moss site type of forest								
Kola	A_0	0.08	–	3.0–3.2	34–52	0.5–1.1	3.3–18.4	4.0–19.7
penin-	A_2	1.4–1.5	5–6	3.2–3.5	0.3–2.0	<0.1–0.1	0.4–0.8	0.8–0.9
sula	B_1	1.5–1.7	8–9	4.7–4.9	1.1–3.6	<0.1–0.1	0.2–0.8	0.2–0.6
SW of	A0	0.08	–	4.6–4.7	nd	1.0–1.5	11.5–17.5	1.2–3.8
Western	A_1A_2	1.0–1.5	6–15	4.0–5.5	0.1–3.5	<0.1–0.1	3.4–3.8	0.4–0.6
Siberia	B_1	1.5–1.7	6–10	4.5–5.5	0.1–0.6	<0.1–0.1	2.0–2.6	0.2–0.4

(1) Particle size fraction < 0.01 mm
(2) 1N KCl extraction
(3) Determined by the Tjurin method
(4) Determined by the Kjelldahl method
(5) Determined by the trilonometric method in 0.01 N NaCl extraction
\# Ca + Mg
nd no data

Pine forests of lichen site type preferably cover summits and upper parts of southern and western slopes (Fig. 1) of hills and high plains, where ground water level is under 3 m. These sites are marked by well-drained podzolic soils (Table 2).

Pine forests of green moss site type are typical to the northern and eastern slopes of hills (Fig. 1) and plains (the ground water level is on the depth of 1.5–2 m). Soils at this study sites are moderately drained podzolic ones (Table 2).

Tree stand characteristics of the main studied site types (lichen and green moss) are given in Table 3.

The undergrowth in lichen Scots pine forests in both regions is usually absent, or remains within 1 %, if found; in green moss pine forests the protective coverage of the undergrowth is about 1–5 % (*Sorbus aucuparia* L. or *Sorbus sibirica* Hedl., *Salix caprea* L., *Juniperus communis* L.).

Regardless of the forest type, the principal dominants of the dwarf shrub and herb stratum in the Kola peninsula are species of two families: *Ericaceae* Juss. and *Empetraceae* S.F.Gray: *Empetrum hermaphroditum* Hagerup, *Vaccinium vitis-idaea* (L.), *V. myrtillus* (L.), *Arctostaphylos uva-ursi* (L.) Spreng., *Calluna vulgaris* (L.) Hull. The total projective coverage of the stratum amounts to 13 % in lichen type and 28 % – in green moss type.

In the south-western part of Western Siberia the principal dominant of the dwarf shrub and herb layer in Scots pine forests of lichen site type is *Vaccinium vitis-idaea*. The dwarf shrub and herb layer of green moss Scots pine forests dominates by *Vaccinium vitis-idaea* and *Vaccinium myrtillus*; *Lycopodium annotinum* L., *Calamagrostis arundinaceae* (L.) Roth are characteristic but considerably less abundant species. The total projective coverage of the stratum amounts to 10–15 % in lichen site type and 30–40 % in green moss site type (Zubareva 1960, Sannikov and Sannikova 1985). At the initial stage of recovery process in green moss forests of this regions the share of herbaceous plants in the total cover of the layer may be up to 50 %.

Species composition of the moss-lichen layer of pine forests in both regions studied are similar. The principal dominants of the moss-lichen layer in forests of lichen sites are the following species: *Cladonia deformis* Hoffm., *C. cornuta* (L.) Hoffm., *C. crispata* (Ach.) Flotov, *C. gracilis* (L.) Willd. at fire age of less than 40 years, *C. mitis* (Sarndst.) Hale et W. Culb., *C. rangiferina* (L.) Nyl., *C. uncialis* (L.) Wigg. at fire age of 60–90 years, *Cladina stellaris* (Opiz.) Brodo at fire age of more than 120 years. The moss-lichen layer in green moss pine forests is dominated by *Pohlia nutans* (Hedw.) Lindb., *Polytrichum juniperinum* Hedw. and *P. piliferum* Hedw. at fire age of less than 40 years and *Pleurozium schreberi* (Brid.) Mitt., *Dicranum* spp. at fire age of more than 60 years. The total projected coverage of the moss-lichen layer in Scots pine forests reaches 70–90 %.

Table 3. Selected data on tree layer of Scots pine forests in the Kola peninsula and South-western part of Western Siberia (from data of authors and data reported by Zubareva 1960; Sannikov, Sannikova 1985) (from data of authors and data reported by Bakkal et al. 1990; Sannikov and Sannikova 1985).

Region	Stand characteristics: Average age, years	Share of pine, % (1)	Average height, m (2)	Average dbh, cm (2)	Average basal area, m^2ha^{-1} (2)
Lichen site type of pine forest					
Kola peninsula	30–300	90–100	12–14	20–23	20–22
SW of W. Siberia	50–180	90–100	19–21	25–28	25–27
Green moss site type of pine forest					
Kola peninsula	40–300	80–90	16–20	27–30	27–32
SW of W. Siberia	50–180	80–90	23–34	28–36	30–33

(1) Woodstands of Scots pine forests in the Kola peninsula have an admixture of spruce (*Picea abies* (L) Karst., *Picea obovata* Ledeb.) and (or) birch (*Betula subarctica* Orlova), in south-west of Western Siberia – of spruce (*Picea obovata*) and (or) birch (*Betula pendula* Roth).
(2) The data for woodstands of 50–200 years old.

2.2 Sampling Methods

Forest litter thickness was defined as the interval between the soil surface and mineral horizon (humus layer is absent in soils of this type) (Nadezjdin 1960, Nikonov 1987), lichen-moss cover and layer of newly fallen needles, leaves, cores and branches having been deleted. Litter thickness was measured in 20–100 regularly positioned points at each sampling site.

Sannikov and Sannikova (1985) measured litter thickness using a special electric probing rod*. In this study litter thickness was measured with a ruler in specially made small soil cuts of 20 cm wide and 20 cm depth; the frontier between the organic and mineral horizons was determined visually. In both cases the accuracy of measurements was about ±0.3 cm, number of observations being 2500.

Fire dating was based on the tree ring chronology, using living trees with fire scars at the radial distance of 50–100 m from sampling site. The age of the last fire was taken to be equal to the difference between the current age of a tree and that at the moment of injuring. In each case being analyzed the age of the last fire, determined in at least 5 of the trees, was one and the same.

2.3 Statistical Analysis

To process the data collecting principles of the single factor gradient analysis was used (Whittaker 1973 a, b). Correlation and regression analyses (Zachs 1976) were performed to examine relationships between the thickness of forests litter and the fire age. Coefficients of the regression equations were compared by the Student's t-test. To indicate the postfire time span where no statistically significant changes in the forest litter thickness (the stabilization of litter thickness) were found the one-way analysis of variance was used (Fisher 1955, Afifi and Azen 1982).

* The frontier between organic and mineral horizons was determined by measuring the voltage drop caused by different moisture content in the two layers (Sannikov and Sannikova 1985).

3 Results

3.1 Kola Peninsula

In forest types being studied initial stages of postfire recovery were characterized by linear increasing of litter thickness (Fig.2a,b,c; Table 4). The average thickness of forest litter and postfire age in lichen, green moss–lichen and green moss site types of Scots pine forests had positive correlation ($r = 0.68$, $\alpha = 0.01$; $r = 0.8$, $\alpha = 0.01$; and $r = 0.91$, $\alpha = 0.001$, respectively).

Thickness of forest litter, averaged 2.6 cm and 4 cm in lichen and green moss–lichen sites respectively at fire age of 90 years and did not change further on. Samples of averages for litter thickness during the period from 90 to 210 years after fire did not differ significantly (Table 5). In green moss site forests litter thickness stabilized more than 140 years after fire, approximating 8 cm. Samples of averages for litter thickness from 150 to 210 years after fire did not differ significantly (Table 5).

Making allowance for uncertainty inherent in small-volume samples and data deficiency for forests of lichen and green moss–lichen site types burned 70–85 years ago and that for green moss site type with fire ages of 100–140 years, the time of stabilization of forest litter thickness should be detected to be equal to 80–90 years after fire for forests of lichen and green moss–lichen site types and 120–140 years for green moss site type.

3.2 South-Western Part of Western Siberia*

In Scots pine forests of lichen site type within the whole studied period (from 5 to 85 years after fire), forest litter thickness increased linearly from 0.5–0.7 cm to 4.5 cm (Fig. 2d; Table 4). The average litter thickness positively correlated with fire age (r = 0.96 , α = 0.001).

In pine forests of green moss site litter thickness increased 100–140 years after fire from 1–2 to 8 cm (Fig. 2e). Within the period from 5 to 140 years after fire the form of the relationship was approximated with a high degree of accuracy by linear equation (Table 4). Correlation coefficient r = 0.88 at α = 0.001. Samples of averages for litter thickness in green moss site pine forests during the period from 100 to 175 years after fire did not differ significantly (Table 5).

Considering the uncertainty inherent in small-volume samples and data deficiency for forests burned more than 100 years ago the time of stabi-

* The analysis performed on the data derived from S.N. Sannikov and N.S. Sannikova (1995, p.46–48 Tables 3, 4).

Table 5. Summary tables of one-way analysis of variance (ANOVA) for forest litter thickness.

Region	Forest type (2)	Postfire time span	Statistics (1) V_1	V_2	F-ratio	Significance (3)
Kola peninsula	L	90–210	1	9	1.06	–
Kola peninsula	ML	90–210	1	5	0.29	–
Kola peninsula	M	150–210	1	4	3.01	–
SW of W. Siberia	M	100–175	1	5	0.60	–

(1) L – Scots pine forest of lichen site type (lichen share in moss–lichen cover exceeds 70 %); ML – Scots pine forest of green moss–lichen site type (lichen share in moss–lichen layer ranges between 30 % and 70 %; M – Scots pine forest of green moss type (lichen share in moss–lichen cover is under 30 %).
(2) Statistics: V_1 – degrees of freedom between groups; V_2 – degrees of freedom within group.
(3) the value does not differ from 0 at α = 0.05

Table 4. Summary of linear regression analysis for forest litter by fire age.

Region	Forest type (1)	Postfire time span	Parameter (2)	Statistics (3) *M*	*S*	*t*	Significance (4)
Kola peninsula	L	5–90	a b	0.81 0.02	0.28 0.005	2.79 3.26	* **
Kola peninsula	ML	5–90	a b	0.7 0.03	0.6 0.01	1.22 3.44	– **
Kola peninsula	L,ML	5–90	a b	0.6 0.03	0.4 0.006	1.64 4.31	– ***
Kola peninsula	M	40–150	a b	0.7 0.05	0.8 0.008	0.89 6.9	– ***
SW of W. Siberia	L,ML	3–85	a b	0.3 0.04	0.2 0.004	1.88 10.28	– ***
SW of W. Siberia	M	6–140	a b	1.27 0.06	0.31 0.006	4.02 9.20	*** ***

(1) L – Scots pine forest of lichen site type (lichen share in moss–lichen cover exceeds 70 %); ML – Scots pine forest of green moss–lichen site type (lichen share in moss–lichen layer ranges between 30 % and 70 %; M – Scots pine forest of green moss site type (lichen share in moss–lichen cover is under 30 %).
(2) a – intercept; b – slope;
(3) M – mean; S – standard deviation; *t* – Student's t-test
(4) * significant at α = 0.05; ** significant at α = 0.01; *** significant at α = 0.001, – the value does not differ from 0 at α = 0.05

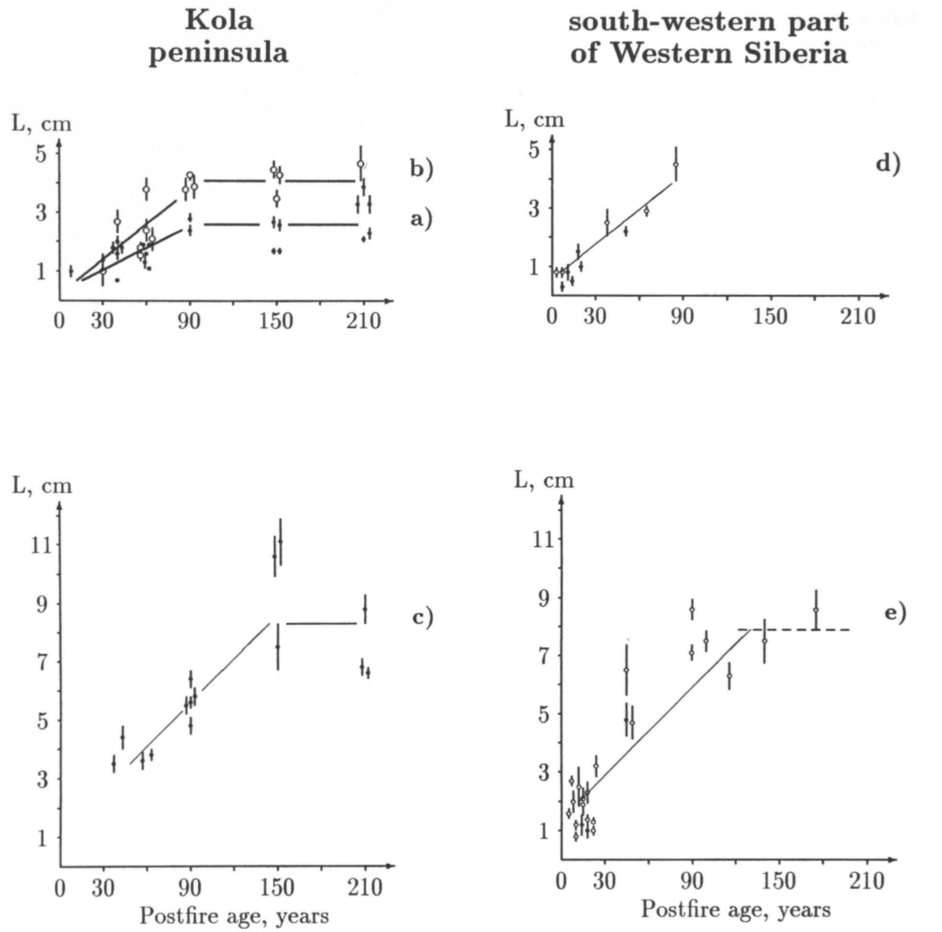

Fig. 2. Thickness of forest litter in Scots pine forests with differing postfire age. Kola peninsula: (a) – lichen site type (share of lichens in moss–lichen cover exeedes 70 %), (b) – green moss–lichen site type (share of lichens in moss–lichen cover range between 30–70 %), (c) – green moss site type (share of lichens in moss–lichen cover is under 30 %). South-western part os Western Siberia: (d) – lichen site type, (e) – green-moss site type (prepared on data derived from Sannikov and Sannikova (1985, Tables 3, 4, p. 46–48).

lization of litter thickness in green moss site type of Scots pine forests in south-western part of Western Siberia can be estimated as amounting to 120–140 years. In lichen site type of pine forests, due to the small time span being investigated, only the lower limit of recovery period was detected: it amounted to 80–90 years after fire.

4 Discussion

Results from these studies show identical course of the postfire recovery process of forest litter thickness in Scots pine forests of two comparable regions despite the differences in mean an-

Table 6. Properties of litter and its store in Scots pine forests of differing types and fire ages in separate geographical regions of Russia.

Region location	Forest type (1)	Fire age (2) years	Characteristics for forest litter: Thickness, cm	Density g/cm³ (3)	Store t/ha	C, %	Store C, t/ha cm (4)	Source (5)
Kola peninsula 33–34°E 68°N	L	50#	1.5	0.12*	17.4	25	2.9	1
Karelia 34°E 62–63°N	L	60–90#	2.0	0.08	16.8	38	3.2	2
Yakutia 122–123°E 60–62°N	L	nd	2.0	0.09*	17.3	nd	nd	3
The same	L	4	0.6	0.09*	5.9	nd	nd	3
The same	L	27	1.2	0.09*	10.7	nd	nd	3
Yaroslavl' region 37–38°E 58–59°N	L	60#	1.4	0.09**	12.9	nd	nd	4
Belorussia 26–28°E 52–53°N	L	38#	2.0	0.10**	20.1	36	3.6	5
The same	L	40#	2.2	0.08**	18.9	nd	nd	5
Kola peninsula 33–34°E 68°N	M	50#	4.0	0.08*	30.9	44	3.4	1
Karelia 34°E 62–63°N	M	60–90#	4.5	0.05**	21.8	40	1.9	2
Yaroslavl' region 37–38°E 58–59°N	M	>40#	4.2	0.09**	38.2	38	3.4	4
Belorussia 26–28°E 52–53°N	M	60#	5.0	0.07*	33.6	45	3.1	5
The same	M	38#	4.0	0.07*	28.3	nd	nd	5
Ukraine 26–28°E 54–55°N	M	>70#	8.0	0.06*	44.3	nd	nd	6
The same	M	30–40#	3.0	0.05*	13.5	nd	nd	6
Krasnojarsk region 96–98°E 58°N	M	50	4.9	0.07	32.3	40	2.6	7,8
The same	M	<5	2.0	0.06*	12.9	nd	nd	8
The same	M	50	3.5	0.07*	25.5	nd	nd	8

(1) L – forests of lichen site type; moss–lichen site type; M – forests of moss site type.
(2) # – fire age was estimated on the basis of analysis of stand age and structure of species composition, and characteristics of moss–lichen cover (Gorshkov 1993)
(3) * – estimated by authors using the data on thickness and store from the source
** – calculated average meaning (from source's data)
(4) The store of carbon in 1 cm of litter stratum per hectare
(5) 1 – Nikonov 1987; 2 – Morozova 1978; 3 – Pozdnjakov 1953; 4 – Koshelkov 1961; 5 – Yurkevich, Yaroshevich 1974; 6 – Miakushko 1978; 7 – Gorbachev, 1967 8 – Gorbachev et al. 1982
nd – No data

nual temperatures (2°C) and other climatic characteristics (Table 1).

Coefficients in the regression equations between the thickness of forest litter and fire age in pine forests of lichen and green moss–lichen types as well as in green moss type of two regions compared (Table 4) did not differ significantly ($|t|$ is equal to 1.58 and 0.23, respectively, $\alpha = 0.05$).

It is significant that not only the limits of recovery time coincide in both northern and southern regions of the boreal zone (90–100 years after disturbance in lichen site type of Scots pine forests and 120–140 years – in green moss site type), but the values themselves (3–4 cm and 7–8 cm respectively).

Indicated values for forest litter thickness agree with the corresponding values for other parts of Boreal Pine Forest. Coefficients of the regression equations ($b_1 = 0.03$ – for lichen site forests and $b_2 = 0.05$ – for green moss site forests) calculated from pooled sample of the data obtained for Karelia, Yaroslavl' region, Belorussia, Ukraine, Krasnojarsk region and Yakutia (Table 6) did not differ significantly ($|t|$ is equal to 1.63 and 1.00, respectively, $\alpha = 0.05$) from the coefficients of corresponding equations (Table 4) derived from the data of authors (the Kola peninsula) and from one of S.N. Sannikov and N.S. Sannikova (south-west of Western Siberia).

An exact coincidence of process of postfire recovery of forest litter thickness in the geographically isolated communities indicates that characteristics of the recovery process are of fundamental nature and do not depend on the location of the community.

The border of both lichen and green moss types of Scots pine forests in the Eastern Europe and the Asia runs in latitude 66–69°N – in the north and 50–52°N – in the south (Lavrenko and Sochava 1956).

The range of the average annual temperature at the extremes of the Scots pine forests (from –8..10°C in the Yakutia to +6..7°C in the Ukraine) exceeds 10°C (Scientific and applied reference book ... 1987, 1988, 1989, 1990). It is evident from the data cited that the predicted increase of the average earth surface temperature in high latitudes will not produce changes in the character of postfire restoration of thickness of the forest litter.

Stabilization of thickness of forest litter is the result of establishment of the equilibrium between synthesis and decomposition of organic matter in forest ecosystem and thus indicates the recovery of its main characteristics.

This suggests that within the natural borders of Scots pine forests, communities of a specific type possess uniform characteristics of recovery.

Variations in the thickness of forest litter during the recovery process in pine forests have made possible to estimate the carbon loss (or store) in natural communities (on the basis of the data on carbon contents in forest litter (Table 6) and data represented in Fig. 2).

According to the data collected, the average density of forest litter in pine forests of Russia averaged 0.08 g cm^{-3}, the store of carbon in 1 cm of litter stratum per hectare averaged 3 tonnes (Table 6). During the period of the recovery, which spans about 90 years after fire in pine forests of lichen and green moss–lichen site type and 140 years in ones of green moss site types, the rate of increasing of carbon store in the forest litter averaged 0.6 t ha^{-1} year^{-1}, 0.1 t ha^{-1} year^{-1} and 0.2 t ha^{-1} year^{-1}, respectively.

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