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THE MORPHOMETRIC STRUCTURE OF THE *LARIX GMELLINII* RECRUITMENT AT THE NORTHERN LIMIT OF ITS RANGE IN THE FOREST-TUNDRA ECOTONE

ABSTRACT. The goal of the research presented herein is the investigation of the morphometric and age parameters of the recruitment of forest stands formed by *Larix gmellinii*, as an indicator of trends in the dynamics of the northern/upper forest boundary in the Russian Arctic, in Northern Central Siberia, in the Taimyr State Biosphere Reserve (the Ary-Mas site), and in the buffer zone of the State Biosphere Reserve “Putorana Plateau”. The morphometric parameters clearly reflect the conditions of growth and regeneration of *Larix gmellinii* at the northern and upper limits of its range. Both sample sites have relatively harsh conditions for growth and survival. Despite coarse soils (high gravel content) of the Putorana slopes, their significant steepness, frequent landslides and creep, the conditions for *Larix gmellinii* growth are better than at the Ary-Mas site. This is also reflected in the rate of regeneration. Thus, at the comparable average height of the recruitment at the forest line, its age on the Putorana Plateau is almost half of that at the Ary-Mas site (9.7 and 17.3, respectively). However, the age of the recruitment at the tree line and at the forest line on the Putorana Plateau is practically the same, while at the Ary-Mas site, the recruitment age at the tree line is 1.5 lower than at the boundary of forest. These results could indicate a trend of *Larix*

gmellinii expansion into the ecotone over the last 20–30 yrs., especially in the mountains of the Putorana Plateau.

KEY WORDS: recruitment of *Larix gmellinii*, morphometric and age parameters, ecotone, dynamics of the northern/upper forest boundary, State Biosphere Reserve “Taimyr” and “Putorana Plateau”, Russian Arctic

INTRODUCTION

Studies on the effect of the recent climate change on ecosystem components are of interest from different perspectives: preservation of traditional forms of nature management of the northern indigenous peoples and biodiversity; extraction and use of resources; the thawing of permafrost; carbon balance; etc. This can be seen in a variety of topics and projects carried out within the framework of the International Polar Year (IPY). One of the issues addressed in the IPY projects *PPS Arctic* (Present Day Processes, Past changes, and Spatiotemporal Variability of Biotic, Abiotic and Socio-Environmental Conditions and Resource Components Along and Across the Arctic Delimitation Zone) and *Benefits* (Natural and Social Science Research Cooperation in Northern Russia and Norway for Mutual Benefits Across National and Scientific Borders) is the study of the dynamics of the northern/

upper limits of forests using data on the tree regeneration (tree individuals <2 m) as an indicator of this process.

These projects have developed methodologies for evaluation of forest stands' conditions, i.e., recruitment, age-structure, and morphometric parameters. These data allow assessing trends in vegetation cover. Changes in climatic and edaphic conditions and/or economic activities affect the ability of forest forming species to regenerate [Benkova, 2006; Bulygin and Yarmishko, 2001; Shiyatov, 2000]. Therefore, the abundance, morphologic features, and age-structure of forest stand recruitment are useful indicators of the recent succession processes and dynamics of the boundaries of the natural zones and belts.

RESEARCH OBJECTIVES AND METHODS

The goal of the research presented herein is the investigation of the morphometric structure of the recruitment of forest stands formed by *Larix gmellini*, as an indicator of trends in the dynamics (expansion or retreat) of the

northern/upper forest boundary in the Russian Arctic. The research used methods in the PPS Arctic and Benefits Programs. The research incorporated the results of the comprehensive field studies in 2010 in Northern Central Siberia, in the Taimyr State Biosphere Reserve (the Ary-Mas site), and in the buffer zone of the State Biosphere Reserve "Putorana Plateau".

In order to implement this goal, the following tasks have been addressed:

1. Investigation of the age of the recruitment of *Larix gmellini* at the northern limit of its range (the Taimyr peninsula, Ary-Mas);
2. Investigation of the age of the regeneration of *Larix gmellini* at the upper limit (elevation) of its range (the Putorana Plateau);
3. Identification of the morphometric and age parameters of the *Larix gmellini* recruitment in the forest-tundra ecotone.

Following the guidelines of the PPS Arctic Project protocol, the samples of the *Larix*



Fig. 1. The area of the study on the dynamics of the northern/upper limits of forests under the PPS Arctic Project

gmellini recruitment were studied within the forest-tundra ecotone at the forest line (i.e. the border of the forest zone or the forest belt) and at the tree line (i.e. the boundary of isolated trees) for three size-groups: height <15 cm, 15–15 cm, and >50 cm, respectively. This methodology was also used in the arctic and alpine forest-tundra ecotones on the Kola Peninsula (Murmansk Oblast) near Lake Kanentiavr and in the Tuliok Ridge, Khibiny Massif (Fig. 1), respectively [Aune, Hofgaard, Söderström, 2011].

STUDY AREAS

The site Ary-Mas (the Taimyr Peninsula, the State Biosphere Preserve “Taimyrsky”) includes the world’s northmost forest “island” and is situated at the southern boundary of the arctic tundra [www.byrranga.ru]. This unique site was first described by A.I. Tolmachev and then was studied in detail by L.N. Tyulina [1937] and the Polar Integrated Expedition of the Botanical Institute of the Academy of Sciences of the USSR [Ary-Mas, 1978]. The forest island is 20 km long and 0.5–4 km wide and is located on the high terrace of the Novaya River. The rest of the territory at this site is occupied by spotty and pit-and-mound sedgy-shrub-moss tundras, polygonal bogs, and, less frequently, by dwarf-birch tundras, floodplain shrubs, nival meadows, and meadow communities of floodplains. Larch forests (or rather sparse forests) in the central part of the “island” are relatively dense (canopy closure 0.3–0.4); they are much sparser to the east and west (canopy closure 0.1–0.2). The tree height is 4–7 m; isolated old larch trees are 10 m high with the trunk diameters of up to 25–30 cm; the average stem diameter is 10–14 cm. Trees of forest fringes with the canopy closure of less than 0.1, along the highest positions of the terraces, are 2–5 m in height; there, they are often lop-sided and have “flag” or “skirt” shapes (Fig. 2).

The understory of the *Larix gmellini* includes dwarf birch *Betula nana*, *Empetrum subholarcticum*, *Ledum decumbens*, *L.*



Fig. 2. *Larix gmellini* (Ary-Mas)
(photograph by A. Usacheva)

palustre, *Vaccinium uliginosum*; in the floodplains, there are *Salix glauca*, *Salix lanata* and, sometimes, brier *Rubus arcticus*, *R. chamaemorus*, *Rosa acicularis*, and *Ribes triste*. The ground cover of the wet sites is dominated by typical tundra hypnum moss (*Hylocomium splendens*, *Aulacomnium turgidum*, etc.); the dry high terraces have an abundance of lichens (*Cladonia stellaris* and *C. mitis*, *Cladonia rangiferina*, etc.) The spotty and pit-and-mound tundras interspersed with open sparse forests are dominated by *Salix alaxensis*, *S. glauca*, *Dryas octopetala* and *D. punctata*, *Cassiope tetragona*, *Carex arctisibirica*, *C. glacialis* and the same moss species as given above.

The Putorana Plateau. The Plateau is a series of basalt formations 2000 m or greater in thickness that were formed beginning in the Carboniferous period [www.oopt.info]. It is dome-shaped and elevated with the highest mark of 1701 m. The territory of the Plateau

is covered by open boreal woodlands with two landscape provinces: East Putorana and West Putorana. The main climatic boundaries divide the Plateau in two directions. The first one defines the boundary between the northern taiga and forest-tundra, extending in the latitudinal direction along the cupola of the Plateau approximately. The second one divides the Plateau into the western and eastern parts between 93-94°E. The provinces have some similar geographic and orographic features but differ in terms of climate, hydrography, soils, and vegetation. The climate of the eastern part is very severe and sharply continental. From October through March, a persistent high-pressure region dominates; the average precipitation is 300 mm. The longitudinal boundary limits the range of the western taiga species: Siberian spruce, mountain birch, Siberian larch, and a complex of associated plants. To the east of this boundary, *Larix gmelinii* dominates in the forest zone, which reflects the increase in the continentality of climate in the eastern direction.

Altitudinal zonality is well pronounced in the vegetation of the Putorana Plateau: forest, forest-tundra ecotone, tundra, and polar deserts. Forest vegetation occupies the valleys: its vertical extent depends on the latitude (increasing to the south), on the amount of precipitation (the tree line is lower to the west), and on the local conditions (exposure, protection from the wind, etc.). On the outer boundaries of the Plateau, the vegetation of the valleys gradually transitions into the zonal. The dominant species in the forest belt is *Larix gmelinii* [Vodopyanova, 1976; Kuvayev, 2006; Malyshev, 1976; Pospelova, Pospelov, 2007].

DATA COLLECTION

The Ary-Mas site. To study the dynamics of the northern boundary of the forest area Ary-Mas located on the east bank of the Ulakhan-Yuriakh River, a 2,550 m long terrain profile was established. The profile with the positions of sample plots superimposed on satellite images is presented in the paper by

V. Kravtsova, O. Tutubalina, and A. Hofgaard [2012]. Along this line, 197 samples related to the *Larix gmelinii* recruitment were studied; of these, 83 were from the forest line and 114 from the tree line; all samples were divided into the three studied size-groups.

The Putorana Plateau site. The upper limit of the forest was studied at the site of the Putorana Plateau in the low-reaches of the Omon-Yuryakh River. To identify the dynamics of the upper forest boundary, a 1,000 m long profile was established. The profile line and the location of the sample plots superimposed on the satellite images are also presented in the paper by V. Kravtsova, O. Tutubalina, and A. Hofgaard [2012]. Along this line, 261 samples of the *Larix gmelinii* recruitment were studied; of these, 116 were from the forest line and 145 from the tree line; all samples were also divided into the three studied size-groups

The field studies involved the identification of the position of each sample and recording of the total stem length and the vertical growth in 2010. The lab studies involved microscopic identification of the stem age (Fig. 3); its maximal, minimal, and the average root collar diameter; and the growth and damage (including frost, animals, etc.) [Budarina, Golubeva, Silenchuk, 2011].



Fig. 3. *Larix gmelinii* (A larch sample. The Putorana Plateau. The tree line. Age is 30 yrs.; diameter 2.12 cm; height 142 cm, the 2010-11 cm shoot length (photograph by K. Silenchuk)

DISCUSSION OF THE RESULTS

The averaged morphometric parameters of the sampled *Larix gmellinii* individuals are presented per area in the table below (Table 1).

The Ary-Mas site. At the forest line, the average age of the recruitment is about 20 yrs. The first group: the average age of the recruitment shorter than 15 cm is 8 yrs. The second group: the average age of the recruitment 15–50 cm in height is 20 yrs. The third group: the average age of the recruitment taller than 50 cm is 32 yrs. The diameter increases with age from 0.15 to 1.2 cm and the height from 13 to 82 cm. At the tree line, the average recruitment age is 19 yrs.; however, the first group of the recruitment, with the heights shorter than 15 cm, is absent. The recruitment of the second group (15–50 cm in height) has the average age of 17 yrs.; the recruitment of the third group (the height is taller than 50 cm) has the age of 24 yrs.; the average height changes from 34 to 76 cm.

The Putorana Plateau site. At the forest line, the average recruitment age of *Larix gmellinii* is 15 yrs. The recruitment shorter than 50 cm has the average age of 10 yrs.; the average age of the recruitment taller than 50 cm almost doubles and reaches 18 yrs. At the tree line, the average age of the recruitment is 12 yrs. The recruitment shorter than 15 cm has the average age of 7 yrs.; the recruitment 15–50 cm in height is younger than 10 yrs. on average; the average age of the recruitment taller than 50 cm is approximately 18.6 yrs. The average diameter of the recruitment increases with age from 0.2 to 1.2 cm; the average height increases from 13 to 93 cm.

The analysis of the morphometric parameters of the *Larix gmellinii* recruitment allows identification of the trends in the forest stand development in this region presented below.

The age of the *Larix gmellinii* recruitment at the tree line and the forest line on the Putorana Plateau is practically the same, while at the Ary-Mas site, the recruitment age at the tree line is 1.5 lower compared to the forest line. This fact suggests expansion of the northern border of forest and the trend of advancement of larch into the tundra plains over the last 20–30 yrs. At the Ary-Mas site, the recruitment of the third group dominates (the height of 50 to 200 cm). The rate of the *Larix gmellinii* recruitment decreases with age; in the second group (15–50 cm), the annual vertical growth is almost 15% of the total stem height, while in the third group (taller than 50 cm), the annual growth of the recruitment does not exceed 7% (Table 1; Fig. 4). There are differences in the growth of the recruitment of larch along the studied profile: the speed (intensity) of the vertical growth increases to the north.

A similar pattern of growth of the *Larix gmellinii* recruitment is observed on the Putorana Plateau. The young growth of the second group prevails quantitatively (the height 15 to 50 cm) (Table 1; Fig. 5). The highest annual vertical growth of 10% is in recruitment of the first and second groups, while in the third group, it does not exceed 6%.

Table 1. The morphometric parameters of the *Larix gmellinii* recruitment. The test plots Ary-Mas and Putorana Plateau

Test plots		Ary-Mas				Putorana Plateau			
Position in the ecotone	H of the regeneration, cm	H, cm	ΔH, cm	Ø, cm	Age, years	H, cm	ΔH, cm	Ø, cm	Age, years
Forest line	<15	13	0.7	0.15	8.0	–	–	–	–
	15–50	36	2.7	0.50	20.0	29.9	4.1	0.33	10.6
	50–200	81.9	4.6	1.20	32.0	93.7	5.7	1.26	18.3
Tree line	<15	–	–	–	–	12.7	1.7	0.2	7.0
	15–50	34	4	0.40	17.3	28.4	2.5	0.3	9.7
	50–200	76.4	7.5	1.40	24.0	93.0	6.1	1.2	18.6

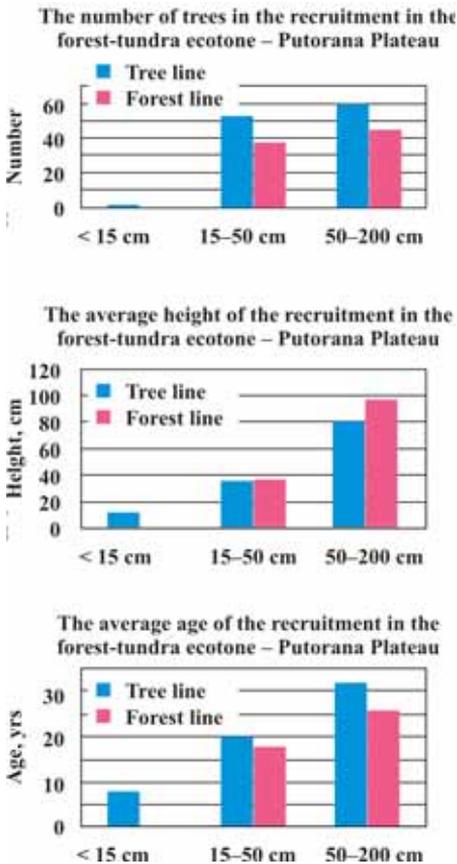


Fig. 4. The morphometric parameters of the *Larix gmellini* recruitment in the forest-tundra ecotone at the Ary-Mas site (Taimyr Peninsula)

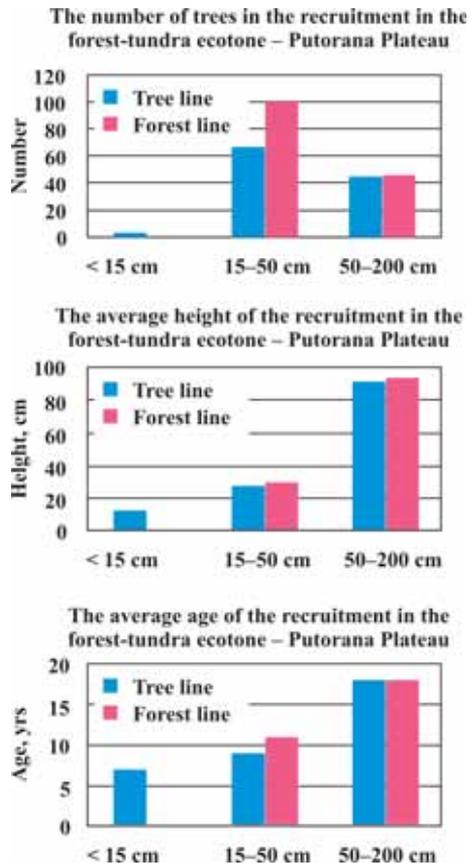


Fig. 5. The morphometric parameters of the *Larix gmellini* recruitment in the forest-tundra ecotone

CONCLUSION

The research on the morphometric parameters of the *Larix gmellini* recruitment at the upper and the northern boundary of the forest-tundra ecotone allowed drawing the following conclusions:

1. For the northern boundary of the forest, the average age of *Larix gmellini* in sparse forest is 26 years; it is 32 years for the tree line. The recruitment with the heights of 50–200 cm dominates; the average height is 81 cm and 78 cm in the open stands and the isolated trees, respectively. The vertical growth of the recruitment differs and increases in the northern direction.

2. For the upper forest boundary, the average age of the *Larix gmellini* recruitment is 19 yrs. (forest line) and 13 yrs. (tree line).

The recruitment with the height of 50–200 cm dominates. Its average height is 77 cm and 71 cm at the forest line and at the tree line, respectively.

3. The morphometric parameters clearly reflect the conditions of growth and regeneration of *Larix gmellini* at the northern and upper limits of its range. Both sample sites have relatively harsh conditions for growth and survival. Despite coarse soils (high gravel content) of the Putorana slopes, their significant steepness, frequent landslides and creep, the conditions for *Larix gmellini* growth are better than at the Ary-Mas site. This is also reflected in the rate of regeneration. Thus, at the comparable average height of the recruitment at the forest line, its age on the Putorana Plateau is almost half of that at the Ary-Mas site (9.7

and 17.3, respectively). However, the age of the recruitment at the tree line and at the forest line on the Putorana Plateau is practically the same, while at the Ary-Mas site, the recruitment age at the tree line is 1.5 lower than at the boundary of forest.

These results could indicate a trend of *Larix gmelinii* expansion into the ecotone over the

last 20–30 yrs., especially in the mountains of the Putorana Plateau and is likely primarily associated with the climate change because anthropogenic impact on the vegetation cover in the conditions of the Reserves' regime is practically absent. However, a firm conclusion can't be made, as the mortality rate within the three size groups of recruiting larch is unknown. ■

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