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Brief Communication

Dynamics of Siberian Fir Stands in Forest Ecosystems of Eastern Sayan Spurs

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Abstract

Dynamics of Siberian fir stands in forest ecosystems of the Eastern Sayan spurs were studied before and during the period of polygraph infestation.

Introduction

Abies spp. are highly vulnerable to the impact of both abiotic and biotic environmental factors. The decline of *Abies alba* Mill. - 'Tannensterben' was described at the northern limit of the range in the late nineteenth century, and since the 1970s degradation processes have spread to the main range [1-5]. Although the silver fir is not endangered, its numbers and distribution have declined catastrophically over the past 200 years. This is thought to have occurred as a result of environmental stresses, logging, air pollution, genetics, damage by insects and animals as well as silvicultural preferences in favor of other conifers, mainly Norway spruce in the second half of the 20th century [6-18]. In spruce-fir forests of the Far East Abies nephrolepis (Trautv.) Maxim die-off is noted, in the east of North America during intensive thinning of stands of red spruce (*Picea rubens* Sarg.) die-off of associated fir species is noted, and in the east - in the area of the Eastern Himalayas *Abies densa* Griff. dies off. [19-23]. Thus, disturbances of homeostasis and decline of *Abies spp*. are now clearly observed in different regions, namely in the Alps, Himalayas, Appalachians, Sayans, Sikhote-Alin, Altai, and Khamar-Daban. In the last two decades, damage to Siberian fir stands (*Abies sibirica* Ledeb.) by the invasion of *Polygraphus proximus* Blandf. has become catastrophic in several regions of Siberia against the background of disturbance of homeostasis and reduction of stability of forest ecosystems [24-26].

The results of the monitoring of the vitality and sanitary status of dark coniferous stands of the spurs of the Eastern Sayan (territory of the Krasnoyarsk Stolby National Park) before the invasion (1992-2004) as well as during the period of intensive Siberian fir trees infestation by *P. proximus* (2019-2021) are presented. The study area is located on the southwestern border of a large industrial center - the city of Krasnoyarsk. Life status was assessed according to the scale of V.A. Alekseev [27] based on the weighted average index of trees of different categories (L). The index was calculated for each plot taking into account tree size according formula: $L=100_{v1}+70_{v2}+40_{v3+}5_{v4}/V$, where v1 is the volume of wood of healthy fir trees at the plot, v2, v3, v4 - the same for damaged (weakened), severely damaged and dying trees, 100, 70, 40 and 5 are coefficients expressing the vitality of healthy, damaged, severely damaged and dying trees (200-250 trees per each plot), %; V is the total wood stock in the stand at the plot in m^3. When L is 1% - 0.8% the stand vitality is considered as healthy, 0.79-0.50 of the stand is considered damaged (weakened), 0.49% - 0.20% - severely damaged, and at 0.19 and below - completely dead. The sanitary condition was assessed also by damage by phytopathogens (*Melampsorella caryophyllacearum* Schrot. = *Melampsorella cerastii* Wint.) and pests (*P. proximus, Monochamus urussovi* Fisch.).

Discussion

The assessment showed that only stands in the suburban area of Krasnoyarsk were damaged before the invasion started (before the 2010s). In the northeastern part, close to the city, the vitality of the stands decreased to 0.7-0.8. The phenomenon was accompanied by biotic damage by rust cuncer (*M. cerastii*), *M. urussovii* as well as *Durandiella*

sibirica Chabounine in the Kuznetskii Alatau range. During the invasion, the mortality of the stands increased to severely damaged (L = 0.49–0.2) or destroyed (L below 0.19). The sanitary condition of the fir stands, according to the weighted average index (K_{ai}), ranged from severely weakened (K_{ai} = 2.9–3.3) to dry (K_{ai} = 4.1 – 4.5). The proportion of fir trees that were broken by the wind ranged from 3.8% to 7.5%. Different growth conditions were associated with damage. Rot and cancer diseases contributed to the damage, actively affecting not only old trees but also young ones (12-16 cm in diameter). The progressive dying of the Siberian fir is caused by a complex of factors. The role of the trigger is played by the *P. proximus*, the pathological decline of which varied from 79.5 to 96.4% depending on the plot. The most harmful diseases are stem and root rot. According to the integral assessment (K_{ai} = 4.7 and 5.0, respectively), the condition of the fir trees affected by these diseases is considered dead.

The large-scale nature of Siberian fir damage points to causes of a global nature, as droughts were primarily considered [28]. However, special studies of climatic indices characterizing wet/dry habitat conditions (AMI, SPEI) show that in the Altai-Sayan mountainous country, they have never reached critical values for the species existence (AMI ≥ 2.25), and the years of onset of desiccation, as a rule, do not coincide with periods of drought (SPEI ≤ -1.5) [29,30]. Thus, the hypothesis about the weakening and drying of Siberian fir in the mountain systems of South Siberia due to droughts as well as increasing aridity of climate can be rejected. Fernandez [31] once proposed a theory of the damage and death of forests under the influence of air pollutants, which was brilliantly confirmed by the example of modern Siberian fir death in Siberia. Previous studies have shown an imbalance in the elemental composition of spruce needles [32]. It has been shown [25,33] that in Western Siberia, *P. proximus* damages not only trees with rots, but primarily thin-barked and thin-skinned trees, as well as trees with increased growth intensity, and foci of mass reproduction, the pest affects both adult trees of any age and medium and large young trees even before entering the seed-bearing phase. A similar picture is observed in the present study in the spurs of the Eastern Sayan. Large-scale intensive drying dramatically reduces the number of seed-bearing trees.

Conclusion

Abies ssp. has been extensively damaged in the eastern Himalayas, Central Europe, North America, and the Russian Far East and is an excellent indicator of disturbance to forest ecosystem homeostasis. Siberian fir tree damage, including by phytopathogens, led to the creation of risk zones over vast areas, which, along with climatic conditions favorable for the survival of the *P. proximus*, contributed to infestation and, as a consequence, their intensive fall. Both climatic and anthropogenic (air pollution) causes of forest dieback were considered. The evaluation of climatic indicators showed the failure of the hypothesis of the influence of climatic changes on Siberian fir mortality. The decline of Siberian fir trees, including by phytopathogens, led to the creation of risk zones over vast areas, which, along with climatic conditions favorable for *P. proximus* survival, contributed to invasion and, as a consequence, intensive forest reduction. Large-scale intensive damage dramatically reduces the number of seed-bearing trees, which creates problems for natural regeneration, as the surviving undergrowth and small trees cannot support stand regeneration. Such areas with dying stands return to the early stages of forest succession, with unstable chances for the formation of new forest ecosystems until conditions favorable for reforestation processes are formed again.

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