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CONDITION OF FOREST ECOSYSTEMS IN THE ZONE OF AERIAL EMISSIONS' IMPACT OF THE NORILSK MINING AND METALLURGICAL INDUSTRIAL COMPLEX. First communication

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In the study, based on the analysis of literary sources and the own research materials, the characteristic of the environmental situation in Taimyr is done, in connection with aerial technogenic impact of the Norilsk mining and metallurgical industrial complex. The dynamics of forest condition over the past decade in the area close to 200 km or more from the plant were evaluated. The analysis was performed taking into account the landscape structure of the territory. The progressive drying of the large areas of the northern forests since the early 80 is registered. In the article, according to the literature reviewed, the structure, dynamics and distribution of air industrial emissions of the Norilsk mining and metallurgical industrial complex «Norilsk Nickel» is analyzed and presented. Further, the authors considered the impact of air industrial emissions of Norilsk industrial region on the forest ecosystems of Taimyr. The focus is on the main forest-forming tree – Siberian larch *Larix sibirica* Ledeb. It is noted the complete absence of the larch undergrowth in the area of industrial pollution. Investigation of the technogenically damaged forests was carried out on the basis of dendrochronological research at six different points on different distances from the city of Norilsk, mainly to the south and east of the metallurgical plant. One study point (sparse larch community) is located 5 km north-west of Norilsk. We investigated stands of varying degrees of damage, including completely dead. It is shown, that outside the area of Norilsk mining and metallurgical industrial complex impact there were no signs of damage to the foliage of the trees and on the contrary, in the area of air pollution (Khantaiskoe Lake), forest stands are largely affected. The main damaging agent is sulfur dioxide.

Keywords: *industrial aerosols, northern forests, ecological catastrophe, Norilsk mining and metallurgical industrial complex, Taimyr.*

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INTRODUCTION

In recent years, it has been completed extensive research on the negative impact on natural ecosystems of Taimyr by the companies of Norilsk Industrial Region (NIR). Especially versatile and in-depth research, since 2001, conducted scientists of V. N. Sukachev Institute of Forest, Siberian Branch of the Russian Academy of Sciences (IF SB RAS), summarizing the results of their research in special theme issue of the *Sibirskii Ekologicheskii Zhurnal* (Sib. J. Ecol.). 2014. N. 6 (in Russian), as well as in the translated to English version of the journal – Contemporary Problems of Ecology. 2014. N. 6.

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In the introductory article of the journal issue, in addition to IF SB RAS researchers, also participated scientists of the Central Siberian Botanical Garden, Siberian Branch of the Russian Academy of Sciences – Michael Yu. Telyatnikov and Eugene V. Banaev (Telyatnikov et al., 2014). Their article provides a brief description of the natural ecosystems of the north of Central Siberia: arctic deserts, tundra, forest tundra, northern boreal forests and wetland complexes. The main destabilizing factors of vegetation, soils and waters classified as gaseous and dust emissions of sulfur dioxide (96–98 % of all gas emissions), chlorides, phenols and heavy metals. It is stressed in the air oxidation of sulfur dioxide to sulfuric acid, which is extremely dangerous to the plant foliage. It is noted that in this natural zone sharp fluctuations in weather conditions are typical, which further worsens the life of plants.

Other articles of the issue were prepared by IF SB RAS researchers. The article of Alexander S. Shishikin, Anatolii P. Abaimov and Alexander A. Onuchin (Shishikin et al., 2014*a*) reviewed the methodology and principles of natural ecosystems research in the areas of extreme technogenic impact. The classification of territory by degree of disturbance is developed. Especially valuable is the map of distribution of all observation points (key sites and plots) on the territory and zoning for the four levels of disturbance. For the first time for that object, numerical score assessment of damage by the landscape components of ecosystems is proposed.

Considerable work on the classification of forest conditions south of the Taimyr Peninsula and the plateau of Putoran based on GIS technology, research team of a complex unit performed, represented by Vera A. Ryzhkova, Irina V. Danilova, and Michael A. Korets (Ryzhkova et al., 2014). For the first time using an automated approach for differentiation of climatic, orographic, soil and hydrological data, using existing rich source database of literature and field expedition materials, conjugate analysis realized for subsequent simulation of site conditions with access to the forecast of vegetation dynamics.

According to the materials of field research in key areas in 2001–2004, and remote sensing data for the period of 1998–2004, the degree of disturbance of vegetation cover has been estimated, using multispectral satellite imagery and multi-temporal ENVISAT MERIS and SPOT VEGETATION satellite data. The numerical score assessment of vegetation disturbance completed and the estimation of pollution levels of the territory done, as well as zoning implemented (Korets et al., 2014).

Alexander V. Pimenov, Dmitri Yu. Efimov, and Vyacheslav A. Pervunin (Pimenov et al., 2014) in their work, consider in detail topographic and ecological differentiation of vegetation in the Norilsk industrial region and phytocenoses' response to the technogenic impact.

In the article of Estella F. Vedrova and Lyudmila V. Mukhortova (2014), the results of biogeochemical assessment of forest ecosystems in the zone of impact of Norilsk industrial complex are presented. It is shown, that the role of phytomass carbon deposited by the pollution gradient decreases by almost 30 times. Dead plant material acts as sorption, sedimentation, and mechanical barrier, where the heavy metals and sulfur are concentrated.

The dynamics of the Siberian larch drying in the zone of technogenic emissions' impact were studied by Alexander V. Kirdyanov, Vladimir S. Myglan, Alexander V. Pimenov et al. (Kirdyanov et al., 2014). According to the analysis of radial increment, the dynamics of larch stands' die-off in the main direction of the technogenic emissions' transport have been reconstructed. It is revealed, that mass tree mortality began in the 60s, and the complete destruction of the stands took place by the middle of the 70s. At the most distant site (85 km), a surge of larch death occurred in the period from 1975 to 1980, and by 2004 only 23 % of the trees were alive.

Pollution of peat deposits in forest-tundra is discussed in the article of Lyudmila V. Karpenko (2014). Tamara T. Efremova and Stanislav P. Efremov (2014) made an ecological and geochemical assessment of contamination levels of heavy metals and sulfur in hilly peat bogs of the southern Taimyr. It was determined that active accumulation of heavy metals and sulfur in the upper layer (5 cm) and less lower (15 cm), and the total technogenic flow passing through the peat sediments does not exceed 30–35 cm.

Yuri I. Ershov (2014) produced the ecological and geochemical assessment of permafrost soils of the Central Siberian Plateau. He evaluated the contribution of the major sources of heavy metals and sulfur in the frozen ground, determined spatial and subsurface concentration of the elements, and completed soil-geochemical zoning.

Tatiana V. Ponomareva et al. (2014) completed ecological and functional assessment of soil condition in the area of aerial technogenic impact of Norilsk industrial complex. Structural and functional abnormalities in the soil microbial complex with high damage of vegetation are pointed out in the article.

Condition of animal population in the impact zone of Norilsk industrial complex is discussed in the article of Alexander S. Shishikin, Dmitrii N. Oreshkov, and Elena S. Uglova (Shishikin et al., 2014*b*). Natural abundance of animals, their influence on species composition and population characteristics studied. Conjugate analysis of the vegetation and animal population parameters completed.

In the article of Andrei V. Gurov, Nina N. Gurova, and Viktor M. Pet'ko (Gurov et al., 2014) the results of 2008–2009 expedition research on arthropod fauna in key areas is presented. The composition and biodiversity of entomological complexes, trophic activity, depending on the remoteness of sources of pollutants emissions, have been evaluated. Attention is drawn to the need of monitoring.

The article of Irina N. Bezkorovainaya (2014) devoted to the study of soil invertebrates in forest-tundra in the conditions of technogenic pollution. With the increasing distance from the source of contamination, density of soil invertebrates is greatly increased. The dependence of meso- and microfauna from the concentration of heavy metals (Ni, Co, Cd, Pl) in the litter is revealed.

Alexander A. Onuchin et al. (2014) studied pollution of snow cover in the zone of impact of enterprises of the Norilsk industrial complex. The composition and content of pollutants in snow samples have been determined. Regional maps of the distribution of heavy metals and sulfur were created. It has been revealed that dust emissions are deposited close to the enterprises (7 km), and aerosols and gases are transported over long distances (sulfur marked at distances of over 400 km), up to the global geochemical cycles.

In the article of Gennadii S. Varaksin et al. (2014) an experience of biological remediation of man-made landscapes in the Norilsk industrial district is discussed. The species of woody plants, that are resistant to industrial emissions in the Norilsk industrial district were determined. The possibility of biological reclamation in heavy soil and hard climatic conditions was shown.

Thus, a team of scientists made a significant amount of research, which is important for the understanding and evaluation of technogenic disaster that has occurred. Especially in terms of easily vulnerable and hard to restore nature of the Far North. A number of works presented by many years research and many have pioneering status. We can say that these studies are of lasting historical scientific and practical value.

In recent years another unexpected danger to Taimyr forests outside the zone of Norilsk industrial enterprises has been revealed (Lovelius et al., 2009). The northernmost in the world larch forest island in southern tundra (Ary-Mas and Lukunsky) has been seriously damaged by hares (*Lepus timidus* L.) in winter lack of fodder. Hare nibbles of a living part of the tree bark leads to die-off the large number of trees (up to one third of the tree stands). The area is located in the Taimyr State Nature Reserve and therefore all hunting is prohibited, but the question arises, what is more important to preserve: the large number of unique larch tree stands or hare population. The answer is obvious.

However, in 2013 there happen an integration of three previously independent nature reserves of Taimyr in to a conglomerate referred to as «Joint Directorate of Taimyr Nature Reserves», with almost complete destruction of scientific departments and sharp reduction in the number of state inspectors in the departments of protection of the nature reserves (Ziganshin, Lovelius, 2015). So, that «rodents of environmental affairs» were among the officials in Moscow, moving nature reserve matters towards commercialization.

RESULTS AND DISCUSSION

In the result of the strong industrial exploration of mineral resources of Taimyr thousands of ha of plant cover and soil were dead and damaged (Savchenko, 1998). According to the data of S. L. Menshikov (2004) the total area of damaged forests has been more than 500 thousand of ha.

In the region of Hantaysko-Rybninskaya intermountain basin (Norilsk Valley) the forming of technogenic landscape has been practically finished, it has totally, without doubt, lost any abilities to self-restoration. In Norilsk air for 100 days in a year is polluted on the scale of more than 10 MCP (Gosudarstvennyi doklad…, 1996; Savchenko, 1998).

The result of various anthropogenic industrial impacts became a degradation of the depth of permafrost ground, the development of thermo crust and salt-flotation, air, water and ground poisoning, the pollution of great lakes of Taimyr and rivers with the western and northern sewing.

The monitoring's researches of Taimyr, particularly observations of grazing grounds and sub tundra forests, are necessary because of exclusively high climate-forming role of the northern areas, the large reserves of fresh water, their constant interaction with waters of the World Ocean and the pollution of flowing air mass there.

Forests and forest ecosystems located in the Southern and eastern areas of industrial enterprises on Norilsk mining and metallurgical industrial complex (NMMIC) are affected by the direct and strong impact of industrial aerosols and that's why, according to its modern states, it can be considered as the stated possibilities ecological disaster for all territory of Taimyr including areas of the three largest Russian specially protected natural territories: Taimyrsky, Putoransky, and Bolshoy of the Arctic conservation areas. Acid rains with winds and liquid poisonous wastes (with melting waters) from year to year poison absolutely everything, from the South to the North, a huge territory of continental and seaside Taimyr. That is why to monitor the negative ecological role of NMMIC, we started gathering data and analysis of harmful consequences condition having an example of dynamics of forest plantations' condition in the zone of the most technogenic press of the company's enterprises, with this purpose we decided to use some results of the most serious researches of different authors of the last year and materials of our own expedition's researches of the 90s.

As the global climate of the planet is mostly formed over the aquatic area of the Northern Arctic Ocean and exactly in the continental North, so the role of Norilsk industrial center, which is located in this region, is great because its gross emission of polluting substances into the atmosphere has 14 % of all emissions of enterprises and transport in Russia.

Structure, dynamics and spread of aerial industrial emissions of Norilsk mining and metallurgical industrial complex «Norilsk Nickel». Industrial wastes of NMMIC have 99 % of all industrial wastes in Taimyr. It is 2/3 of all emissions in Krasnoyarsk Krai and 20.4 % of gross emissions of enterprises in Russia. The most part of them is sulfur dioxide. Then it is followed by sulfuric acid, carbon oxide, nitrogen, sulphureted hydrogen, compounds of chlorine, hydro aerosol of nickel, copper, cobalt, lead, selenium dioxide, other chemical substances, dust and carbon-black. The total content of fractions is the following: gaseous substances – 96.1 %, liquids – 2.6 %, solid substances – 1.3 %. In 1995 the total emission of polluting agents into the atmosphere of all industrial works in big Norilsk had more than 2 million tones (105 % to 1994). Exactly since that time NMMIC completely stopped utilizing of sulfur from effluent gases that was made in Soviet time and it was very proud of it.

Considering that derivatives of sulfur are the most harmful components of air emissions for plants, we can predict the results that Russia could have in future, meaning the preservation of its Northern forests. With the fact, that the last 25–30 years of using «Nadezhda» mining factory the high sulfurous, the waste compounds of sulfur increased and obviously have increased dramatically the speed of drying of forests on nearby Norilsk areas since the 90s of the XX century. The negative impact of emissions of this work has reached the edges of Northern Evenkia (more than 200 km from Norilsk to the South). From the tens of km of former Taimyr taiga from Norilsk to Hantayskoe water reservoir nowadays there are dry forests. According to the data of V. I. Kharuk et al. (1996) the negative impact of work on the vegetation is observed in the distance of 180 km to the South. By the facts of V. F. Savchenko (1998) observations the main polluting factors in the structure of NMMIC are the metallurgy (67.6 %) and the fuel and energy sector (26.9 %). Thus, they are followed by the building industry (5.1 %) and other sectors (0.4 %). According to his data (the same work) last years (1991–1997) in spite of reducing of production in Norilsk industrial region, the emissions of compounds of sulfur have been reduced to 12–17 %. Nowadays, the manufacture suffers from the high level of accident risk of technological equipment. But from 1965 to 1995 the using of sulfur into the manufacture had been increased for 8 times. The processing of sulfur ingredients per one unit of manufacturing products had been risen to 35 % that increased the emission of sulfur dioxide into the atmosphere. Despite of reducing volumes of work's production, the technogenic pressure on nature is not reduced, particularly on highly feeling plants' groups (forests and reindeers pastures).

Taken in the residential zone[1] of Norilsk MPC (maximum permissible concentration) of harmful chemical substances is the following[2]:

Sulfur dioxide. Average MPC is 0.050 mg/m^3 of average daily calculation (the factual concentration in Norilsk 0.100–0.120 mg/m^3, so it is exceeded 2.0–2.4 times). Maximum single meaning of MPC of sulfur – 0.500 mg/m^3, in fact the monitored ones were 6.010–14.800 mg/m^3 exceed permissible concentration for 12.2–29.6 times.

Sulphureted hydrogen. The average daily concentration 0.002–0.001 mg/m^3, maximum meaning of MPC is 0.008 mg/m^3, in fact it was 0.029–0.064 mg/m^3, exceeded for 3.6–8.0 times[1].

The exceeding of MPC of formaldehyde is for 4.10–4.14 times , of phenol is for 4.70–5.10 times,

[1] Ground areas in the cities occupied by living and social buildings, streets, squares and green plantations of common use.

of chlorine is for 3.30–3.40 times, of nitrogen dioxide is for 4.90–8.85 times, of dust is for 3.20–4.80 times. Therefore, it is clear that there is a deficit of clean air in the city of Norilsk[2].

Consequently, the indicators of the air pollution by industrial emissions are connected with meteorological conditions. So, the casual weather changes (wind to calm, rain or mist), with the same gross emission of pollutants into the atmosphere, can make the air pollution much more.

As it was fairly mentioned by V. A. Savchenko (1998), in past years, because of the hard economic situation in our country, Taimyr service of hydrometeorology was practically destroyed. Consequently, atmosphere pollution indexes (API) and potential of atmosphere pollution (PAP) calculations are based on the accurate and daily consideration of meteorological data of inversion, winds, calms, mists, admixtures in air some chemical compounds and so on, nowadays it is obviously impossible to be calculated with the necessary degree of accuracy. That is why now the monitoring of company's industrial activity impact on the environment is more preferable and safety to do by the studying steps of digression of particular natural communities and fluctuation of boarders and territories of zones of negative impact of summary industrial potential of NMMIC on the vegetation of nearby areas.

Gas-aerosol emissions into the atmosphere have a high migration ability, so it mentions a large area distribution of pollutants, and snow cover helps it transportation because in these climate conditions it accumulates chemical substances coming together with atmospheric precipitation for 7–7.5 months. It was stated (Grebenets et al., 1995), however, that snow cover rarely catches more than 1/3 volume of emissions. The last 2/3 volume of emissions are dispersed into the atmosphere, they come into the regional and global migration cycles forming «accumulated» pollution.

The technogenic impact on nature of Taimyr had begun in the end of 30s years of the last century since the time of the building of enterprises and the beginning of polymetallic ore processing. In the 40s and 50s years the mining-treating enterprises with smoke pipes having height of 138, 150 and 180 m were built. To the 70s the negative impact on vegetation of the region was weak, but with the commissioning of working mines and mining refinery «Nadezhdinsky» (in 1980 with 250 m pipe), there was a sharp rise of the negative impact of NMMIC on the vegetation because of the high sulfur content from using ores in the processing again. According to the enterprise's data (Savchenko, 1998) of annual emission into the atmosphere in the 90s, about 1.9–2.4 thousand tons of sulfur dioxide by T. M. Vlasova and A. N. Philipchuk data (1990), since the beginning of 80s, there was the following increasing of sulfur into the atmosphere (thousand tones): 1980 – 2349, in 1983 – 3998, in 1986 – 4738, in 1989 – 4438 (having solid emissions). In 1985 enterprises put out into the atmosphere 4845 thousand of tons of air emissions that were transferred into the southern direction and were distributed along the area of about 4000–8000 km^2. Upon their data on 93–98 % gaseous fractions consist of sulfur (sulfur dioxide). And by the data of S. N. Menschikov (2004) 3 km in the south from MPC the content of sulphur anhydride in the air was 5 mg/m^3, in the 26 km – 2.25 mg/m^3. Also, by his data the content of sulfur in snow water to the South from the enterprise in 1990 was: 5 km – 19 mg/l; 30 km – 11 mg/l; 80 km – 11 mg/l; 100 km – 11 mg/l; 125 km – 15 mg/l.

Around NMMIC, mushrooms and berries contain salts of heavy metals in quantities exceeding permissible concentration levels (PCL) for 8–25 times (Savchenko, 1998). According to the same work the high-contrast technogenic areas of heavy metals were formed on the 1/3 territory of Taimyr, being in soils, bottom sediments, vegetation, surface waters. Heavy metals are accumulated mostly in the humus soils where they are taken by roots of plants. Mushrooms and berries, having a great ability to accumulate salts of heavy metals (to 100–300 mg/kg of its dry weight), also are able to be an indicator of pollution.

The major flare plumes of the enterprise distribute heavy metals in the distance of 10–40 km, but along the direction of prevailing winds (also the southern and the south-east winds), the content of nickel is higher even in the distance of 200–250 km from Norilsk (Savchenko, 1998).

Air emissions of NMMIC are spread hundreds of km, mixing into the atmosphere, transported on long distances to the North, North-West, South and East polluting air space of Arctic and they are spread on territories of all specially protected natural territories of Taimyr peninsular to Evenkia and to the North to the ocean. According to the data of geologists and foresters, negative consequences of the enterprise's work were seen on the vegetation,

[2] The condition of the air atmosphere pollution and surface waters on the territory of the work of Taimyr regional center of hydrometeorology (TRCGM). Annual works 1989–1997.

soils and waters sometime in the distance of 400 km (Issledovanie …, 1979; Snisar, 1995; Kharuk et al., 1996; Khimichev, 1995).

The impact of air emissions of Norilsk industrial region on forest ecosystems of Taimyr. Forest ecosystems of high latitudes are characterized by the dispersion of wood reserves on the area, its distinctive building and age structure, a weakened ability for self-restoration and higher sensitivity to natural and anthropogenic stresses (Abaimov et al., 1997). Acting in extreme for wood species climate conditions, they are marked by low processes of growth, energy and mass exchange, a weak ability of waters and soils to self-purification, a low biological productivity and limited abilities in utilization and transformation of different coming from outside harmful compounds. On the western area of macro slope of the Putoran plateau between 67°30′–69°40′ N and 88°00′–90°30′ E. forest ecosystems are undergone by intensive direct impact of industrial emissions of enterprises of Norilsk. Meanwhile, nearby forests (the forests of Norilsk Valley) had been dead a long time ago, and the impact of enterprise weakens the viability of the stands located very far from it (100–200 km or more).

Natural conditions. According to V. P. Kutafiev (1970) the territory of Putoran province is characterized by the predominance of 600–800 m levels of the surface folded into traps. The climate is cold, moist enough, in the river valleys, as a result of inversion, it is a sharp continental. The average temperature of January is –27–32 °C, minimum temperature is –64 °C. The average summer temperature of the mid-July is +12–14 °C, the maximum one is +32°C. The number of days in a year with the temperature of over +5 is 70–85, (usually from the 10th of July to the 5th of September). The annual sum of precipitations is 400–500 mm; half of it is in the vegetation season. In this time the western winds prevail. Soils are stony small profile drilling and criozems, more often hard and medium loamy, poorly-drained and wet. The frozen soil is melted to the depth of 40–60 cm in summer.

Forest vegetation. The major of the forest species is larch *Larix sibirica* Ledeb. In the mountains there are: light-coniferous and sparse growth of trees forest belt with sub-belt of spruce-larch forests and larch sparse growth of trees; bush belt with sub-belt of alder-bush and dwarf birch-bush; region of goltsy-tundra forest belt with sub-belt of moss-lichen tundra and mining-and stony deserts. On the Northern border of the region of our researches the higher limit of wooden vegetation is on the level of 200–400 m over sea, in 200 km to the South the forest boarder rises to 500–700 m. Monodominant rare-stand larches are prevailed. Also, mixed birch-spruce larch forests and sparse growth of trees with Siberian pines *Picea obovata* Ledeb. and a fluffy birch *Betula pubescens* Ehrh. are dominated. Mining and flat landscapes are stood out. The productivity of mining forests, as a rule, is low – usually not higher than V– Va productivity classes (bonitet), otherwise, the productivity of flat forests around Hantaika water reservoir reaches III cl. of bonitet. In the flat big-size aged larch forests, birch comes to the II circle. The most productive forest stands are grown on the river and lake banks or they can be met on the trails of slopes, and less productive ones have worse ecotops: surfaces of scarp stony slopes, large stony or marsh flood plain terraces and flat top watersheds.

The particular feature of rare-stand light-coniferous taiga is also the presence of thick undergrowth and even total lack of undergrowth of the major species. The natural renewal is presented mostly by planting birch and pine. In the undergrowth of 0.5–1.5 m everywhere dwarf birch *Betula nana* L. and bush willows (*Salix lanata* L., *S. phylicifolia* L., *S. glauca* L., and others) are dominated, and rarely bush duschekia *Duschekia fruticosa* (Rupr.) Pouzar, the Siberian juniper *Juniperus sibirica* Burgsd. and wild rose *Rosa acicularis* Lindley can be met. Moss-bush and bush forest types are widely spread. In the dead and heavily damaged vegetation zones in the over soil cover, C*alamagrostis* is dominant.

The larch is successfully restored in the natural way only after fire. The new larch undergrowth results from incomplete burnout, and then various aged and conditionally varying plantations with birch and pine are formed from the rest of mother stands and young growth of the new generation and its part is growing. The average age of larch is varied from 90–320 years, the birch – 80–200 years, the admixture of pine is the most age varying.

In our opinion, fires help strengthen the position of the major species – Siberian larch, and the durable plantation development without fire leads to its change by the bush vegetation, planting birch or more shadow-resistance pine. As bushfires on the studying territory hardly take place, here everywhere overripe mixed stands dominate, from which natural degradation under the impact of pollutants additionally quickens (grows), especially in flat forests of Hantaika-Rybninskaya hollow.

It is known that in Europe and in Russia the evaluation of crown trees condition and changes of annual growth in diameter of trunk with a weak degree of tree damage has not given perceptible indication results (Pollanschutz, 1971; Ziganshin, 2008). That is why it is worth studying background and damaged forests in extreme climate condition of polar taiga, because the tree death here is the result of joint impact of loading and tense factors of environment (Schweingruber, Voronin, 1996; Tscvetkov, 2003).

The research of the condition of anthropogenic damaged forests. The natural habitat area of Taimyr damaged forests mostly in the South of Norilsk that is connected with prevailing winds. Based on witness' observations, the stand drying started since the 50s of the last century. To the end of the 60s, the area of dead forests was 5 thousand of ha (Kharuk et al., 1995, 1996). The zone of total forest stands' death in 1993 was stretching on 90 km to the South of Norilsk, and visible forest damages of technogenic impact had been seen in the distance of 170 km from the city. The area of dead and damaged plantations since 1976 to 1990 had been increased from 322 thousand ha to 550 thousand ha while the area of dead trees in 1989 had been 283 thousand of ha according to the data of I. V. Simachev et al. (1992), and also the work of A. P. Ivshin and S. G. Shiyatov (1995). These researchers, by using methods of dendrochronology, stated that till 1967 on all studying areas (see below) the quantity of disruption was 0.2 and 3 % from the number of trees in the plantations. From 1970 the disruption percentage had been growing and to 1982 all trees on many of them died.

The dendroindication research, mentioned above by authors (Ivshin, Shiyatov, 1995), were done on the taken sawed timber samples and kernel samples from trees in different points to the East and the South of Norilsk:

1. *The Lama Lake*, coast. Spruce-larch-birch plantation on the gently sloping Southern part, 80 km to the East of Norilsk. The forest stands are without any damages.

2. *The Kulumbe River*. Larch-spruce community is on the crushed stony river terrace of 160 km to the South of Norilsk, on the way of prevailing transfer of air masses. The forest stand is with the first symptoms of damage (chemical burns of needles of larch, dried pines).

3. *The Hantayskoe Lake*. Larch-spruce-birch stand on the marsh plain of 110 km to the South of Norilsk on the way of the main atmosphere transfer, The most part of larches and 50 % of birches having a strong damage or dead.

4. *Norilsk region*. 70–90 years old rare larch community on the higher boarder of the forest (400 m below the seacoast) on the humid northern slope of 5 km to the North-West of Norilsk. Outside the zone of action of the main transferring. In the stand there are a lot of drying forests. The majority of dwarfish bushes have necrosis of leaves.

5. *The Rybnaya Ri*ver: 1) last larch with willow community is on the over humid river terrace (0.5–1.0 m above seacoast). Dead forest of 40 km to the South of Norilsk in the zone of the main transferring; 2) last larch forest with dwarfish birch in the undergrowth and the crowberry in the grass cover. The age of larch is 60–80 years. The dead forest and dead dwarfish bushes.

6. *The Valek River*. The immense massive of dead birch forest of 40–60 years on the fresh humid southern slope, of 12 km to the North of Norilsk. Outside the zone of the main transferring. The majority of trees have been dead recently.

On the micro cuts of wooden samples from the different points of research, the number of anomalies has been found: extremely narrow year circles, thinning of cell walls, and the damage of the formation of water-conducting system (trachea and vascular).

The study and the damaged forest area is shown on Fig. 1.

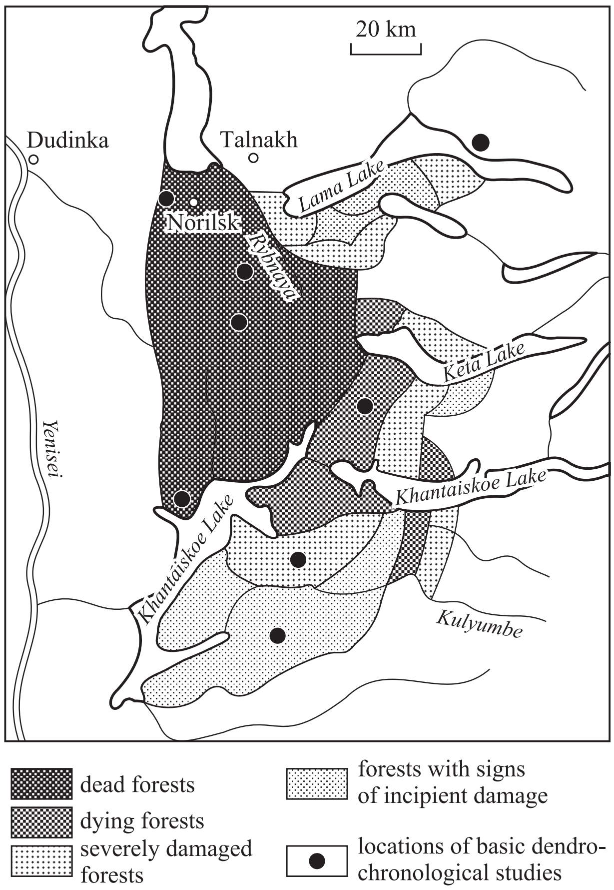

Fig. 1. The damaged forest area south of Norilsk in the end of XX century, 58–70° N, 88–92° E (Ivshin, 1993; Schweingruber, Voronin, 1996).

The consequences of technogenic pollution by the data of dendrochronological research.

1. *The Lama Lake*. The residential area is mostly located outside of the zone of emissions impact of NMMIC. In summer of 1991 trees didn't have traces of damage of leaves apparatus (necrosis). The growth of trees had been in the limits of standards, the bedding hadn't included any anthropogenic pollutants.

2. *The Kulumbe River*. In the structure of wood of over aged trees of pine and larch there wasn't pathology made by an anthropogenic impact. The forest stands had two generations. The younger one was born in 30–40 years, the oldest one (mother) was born in the end of the nineteenth century. To the 1950s it had been growing well, and after the bushfire of 1968 it had been the sharp reduction of the radial growth that resulted to the trees death.

The young generation had had the decrease of growth since 1989, and to 1991 30 % of trees had been dead, the others 70 % of trees had had a needling not more that 10 %, so in 1992 they had to be dead-dried.

These forest stands are impacted by regular anthropogenic emissions, some examples of the second needling of larch. The main agent of damage of the assimilation apparatus was sulfur dioxide.

3. *The Hantayskoe Lake*. The spruce forest stand aged of 40–60 years. The periods of growth fall of various durations had been noticed since 1980. Only one of studied trees died after 1980, the death of others had been between 1986 and 1990, after the end of the forming of growth rings. Though, the defoliation of the rest of living trees are nearly the same and have 50 %, the options of growth rings are very different in trees. From 10 studied trees, 4 trees have growth reduction since 1987 to 1988, and 6 trees kept the normal growth.

Forest stands were considerably damaged by atmosphere pollution. By the way, in this area the larch has the least resistance, and the pine has the highest. The birch is in the middle position.

The inside differences of trees of their individual gas resistance were seen. Some single living larches can be met among the dead forest stand. And some dried pine trees are in the relatively living spruce forest. In the bedding as also in the area of the river Kulumbe there wasn't a considerable rise of concentration of anthropogenic chemical elements. Therefore, here the main harmful agent is sulphur dioxide (Ivshin, 1993; Ivshin, Shiyatov, 1995; Menschikov, 2004) (Fig. 2, 3).

The brief summary of the dendrochronological research. It is obvious that trees to the South of Norilsk died from the emission impact. First of all, it is shown by the chronology of their death. There up to 1967 there were not facts of the forest drying (Ziganshin, 1996). In 60 km to the South of Norilsk trees had been dead between 1975 and 1985, in 110 km to the South the process of drying had been started in 1980, and in 60 km it had been in 1991.

The main confirming agent was sulphur dioxide, after «such affecting» trees either die immediately or get severe physiological damages, causing the great reduction of its radial growth. In the regions of Taimyr pine is more stable than larch, and the most stable is birch. In the regions of Pribaikalie larch and pine have less resistance to industrial emission than larch (our researches), and in the Western Europe fir tree and pine are also the least stable (according to the research of many scientists in 80–90s of the XX century, included S. Slovik et al. (1992).

The differences of stability are explained by edaphic conditions of larch location in the Northern landscapes, growing mostly on slopes, table lands and frozen valleys, while pine is on the talik locations of the river terraces where the vegetation time is longer and the soil moisture is more available form for plants adoption.

According to our researches of Baikal, trees in the case of the weakness of the anthropogenic pressure may recover their satisfactory physiological condition in some years. But when again it is followed by the new impact damage (like it was on the river Kulumbe in 3 years), trees can be dead because of losing of the reserve of resistance. So, on the river Rybnaya the forest damage had been for some times and it made the forest stands die in 2–4 years.

The pine shows a differentiated reaction for gas damage. Many trees die quickly, the others weakly react to the gas attack. More often after the first gas impact the pine has a growth reduction, and the death is after the next impact. Before death the pine has time to form the late wood, but because of the short period of vegetation it has not enough time to regenerate needles. The part of pines reacts weakly on the second impact of emission.

In the forest shipment there were the following facts. Also the slow-growing (oppressed) trees and quickly growing ones can die at the same time. It is proved in the forests of Pribaikalie (Ziganshin, 1996, 2002, 2008).There is no tie between the size of a tree and its age, and on the other hand, with its gas resistance. The trees having 50 % of defoliation hardly have growth reduction. First of all, the

Fig. 2. Significantly damaged larch forest at the upper part of the slope (Foto R. A. Ziganshin, 2008).

Fig. 3. Relatively healthy larch forest at the plate river terrace (Foto R. A. Ziganshin, 2008).

thick-needled pine may have it. In the locations of the dead forest it is clear that each tree has its own story of the death that is seen in the growth ring and crowns of trees. In one forest stand at the same time one can see not damaged, middle, hard damaged and dead trees of one species in the nearest distance from each other. Here, it is possible that the genetic peculiarities of trees take place. That is why the conclusion about the kind of damage and its intensiveness may be done only on the base of the summary and analysis of the numerous data of the massif.

(To be continued)

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СОСТОЯНИЕ ЛЕСНЫХ ЭКОСИСТЕМ В ЗОНЕ ВОЗДЕЙСТВИЯ ВОЗДУШНЫХ ЭМИССИЙ НОРИЛЬСКОГО ГОРНО-МЕТАЛЛУРГИЧЕСКОГО КОМБИНАТА. Сообщение 1

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На основании анализа литературных источников и материалов собственных исследований рассмотрена экологическая обстановка на п-ове Таймыр в связи с аэротехногенным воздействием Норильского горно-металлургического комбината (НГМК). Дана оценка динамики состояния лесов за последние десятилетия в полосе от непосредственной близости до 200 км и более от комбината. Анализ проведен с учетом ландшафтной структуры территории. Отмечено прогрессирующее с начала 80-х гг. усыхание больших массивов лесов. По литературным данным приводятся структура, динамика и распределение аэропромвыбросов предприятий Норильской горно-металлургической компании «Норильский никель», а по данным авторов рассматривается воздействие аэропромвыбросов Норильского промышленного района на лесные экосистемы Таймыра. Основное внимание уделено главной лесообразующей древесной породе – лиственнице сибирской *Larix sibirica* Ledeb. Отмечено полное отсутствие подроста лиственницы в зоне промышленного загрязнения. Изучение состояния техногенно поврежденных лесов проведено на основании дендрохронологических исследований в шести различных точках на разном расстоянии от г. Норильска, в основном южнее и восточнее металлургического комбината. Одна точка исследований (разреженное лиственничное сообщество) находится в 5 км северо-западнее Норильска. Исследовали насаждения разной степени поврежденности, в том числе полностью погибшие. Показано, что вне зоны влияния эмиссий НГМК не отмечено признаков повреждения листового аппарата деревьев, тогда как в зоне атмосферного загрязнения (оз. Хантайское) древостой в значительной степени пострадал. Главным повреждающим агентом служит двуокись серы.

Ключевые слова: *промышленные аэрозоли, северные леса, экологическая катастрофа, Норильский горно-металлургический комбинат, Таймыр.*