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Original Research

Anthropogenic Impact on the Components of the Forest Ecosystem: On the Example of the Bayanaul State National Natural Park

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Abstract

External anthropogenic factors of influence are: industry, agriculture, hunting and forestry, recreation and other factors, which are responsible for the increasing insularity of most nature reserves. In addition, rural areas have expanded in the last 15 years more than in previous years, indicating a further deterioration of the forest structure and biodiversity of Kazakhstan's important island forests. The study provides a review of research on the study of anthropogenic impact on the components of the forest ecosystem of the Bayanaul forest of Kazakhstan. The degradation of phytocenoses due to the impact of anthropogenic factors has been established. It is shown that the main source of anthropogenic factors is atmospheric air pollution near the highway, forest recreation and the expansion of settlements. In the anthropogenically disturbed areas, soil contamination with heavy metals, a decrease in species diversity, a decrease in projective coverage, and annual growth of Scots pine (*Pinus sylvestris* L), as well as a decrease in renewable forests over the past 50 years, are noted. The average disturbance of the forest was revealed. Further influence of anthropogenic factors may lead to further deterioration of the forest structure and biodiversity of important natural pine forests of the Kazakh Uplands.

Keywords: anthropogenic impact, heavy metals, biodiversity, soil, flora, pine stands, annual growth, renewal, forest degradation

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Introduction

The Republic of Kazakhstan is one of the states with a small percentage of the forest fund. Forests occupy 12.9 million hectares in 2018, which is 4.7 % of the territory of Kazakhstan [1]. Bayanaul State National Natural Park (BSNNP) is located in the south of the Pavlodar region of Kazakhstan, 100 km from the city of Ekibastuz, on the outskirts of the Central Kazakh Uplands. The park was founded in 1985, being the first national park and is one of the specially protected natural territories of Kazakhstan. The reason for the creation of the park was the need to preserve and restore the natural flora and fauna of the Bayanaul mountain range. The island pine forests of the Kazakh Uplands belong to the region of moderately dry steppes with a pronounced altitudinal belt, where pine, alder, birch and aspen forests also grow on granite low mountains. The main forest-forming species is Scots pine (*Pinus silvestris* L.), which occupies 75% of the total forested area. The territory of the BSNNP is distinguished by the uniqueness of individual plant communities and soil diversity – each of the four types of vegetation (forest, shrub, meadow and steppe) is associated with certain soil variants (brown forest and alluvial, forest-meadow, meadow, chernozem) [2].

Motor transport, which has been rapidly developing in recent years, makes a significant negative impact on environmental pollution. Emissions of combustion products of motor vehicles of sulphur oxides and nitrogen oxides, as well as their compounds (photo-oxidants, peroxyacetyl nitrates), not only pollute the atmosphere but also cause significant changes in the plant component of forest ecosystems, there is a decrease in the rate of litter mineralisation [3]. In addition, Kazakhstan is one of the most vulnerable countries to climate change. In recent decades, it has been proven that climate change has a significant impact on forest ecosystems, which can lead to a high risk of destabilisation [4]. Forecast temperature data show that Kazakhstan will also be in the "danger zone" with an increase in temperature from 4.5 to 5.5ºC. With the maximum climate warming scenario, natural zones may move northward by 350-400 km [5]. The area of the steppe zone may be reduced [6]. Monitoring is an important tool for continuous assessment of the state of forest ecosystems, which allows us to better understand the nature of the forest, assess the importance of natural and anthropogenic processes of vegetation formation and make a forecast of the future state of forest ecosystems.

The Purpose of the Study

Studying the impact of anthropogenic environmental factors on the components of the forest ecosystem of Bayanaul State National Nature Park.

Material and Methods

The objects of research were forest ecosystems growing on the granites of the hummock - Bayanaul State National Natural Park (BSNNP) in the Pavlodar region of Kazakhstan. To study the impact of anthropogenic impacts on the components of the forest ecosystem, three sites were laid in the BSNNP, adjacent to the village, the recreational zone and the highway. The control was provided by the sites located in the order of distance from the highway and settlements, located deep in the forest, at a distance of 20-30 km. The selected territories are mainly associations of Scots pine (*Pinus silvestris L.*), with an admixture of aspen and birch. To assess natural and anthropogenic factors on forest ecosystems, generally accepted geobotanical and dendrochronological studies were used according to classical methods [7]. To determine the floral composition of phytocenoses, an herbarium was collected. Plant species were determined during field work using a determinant [8]. The number of renewals was taken into account on sites with a size of 100 m^2 (10x10) m. At the sites, a continuous recount of seedlings and undergrowth of Scots pine was carried out. Trees not exceeding ½ the height of an adult tree were considered to be undergrowth [9]. The recreational assessment of the territory was determined by the method of the percentage of damaged territory as one of the essential criteria for the digression of forest phytocenoses, as well as in connection with its indicator and accessibility [10].

The selection of core samples for calculating the annual growth of wood was carried out according to the standard method adopted in dendrochronology. Cameral processing of the obtained material and core counting were carried out on a semi-automatic LinTab 6 installation with TsapWin software [11, 12]. The content of chemical elements of these soils was determined using an atomic emission spectrometer with inductively coupled plasma SPECTRO ARCOS (Germany). Soil samples were taken from four sites: dunes, natural plains, along auto- and dirt roads. To collect these samples from natural plains, we selected a site subject to low anthropogenic influence and located 15 km from the settlement. When calculating the total pollution index, the toxicity of chemical elements was taken into account and the concentration factor (Cf) was calculated and the level of total pollution was graded. The data of classes and hazard coefficients (toxicity) of metals and gradation are presented (Tables 1, 2).

The determination of the content of heavy metals in various components of the forest biogeocenosis was determined according to the generally accepted method [13]. Statistical processing of the research results was carried out using the Statistica 7.0 software package, etc.

Table 1. Classes and coefficients of hazard (toxicity) of elements.

Hazard classes	Elements	Toxicity coefficient
I	Arsenic, cadmium, mercury, lead, zinc, fluorine	1.5
II	Boron, cobalt, nickel, molybdenum, copper, antimony, chromium	1.0
III	Barium, vanadium, tungsten, manganese, strontium	0.5

Table 2. The level of total pollution of forest ecosystem components.

Pollution level	Total indicator of soil pollution (Z_c)
Low	8-16
Average	1-32
High	32-128
Very high	>128

Results and Discussion

Pollution of the environment by heavy metals is one of the acute environmental problems of our time. Forest landscapes play a special role in this process. The first series of research presents the results of a study of the content of a number of heavy metals in the soil of the Bayanaul SNNP. The background content of heavy metals was taken to be their content in the natural zone, which is considered far from the anthropogenic zone. The data in Table 3 show that in the soils of all the studied areas of the BSNNP forest the highest concentration in the series of studied metals is shown by manganese and it ranges from 51-152 mg/kg. The maximum value in the park's soil of about 152 mg/kg shows the content in the soil along the highway, and it is higher than the TLV by 11.9 mg/kg. In second place is zinc and its content is in the range of 2.3-7.3 mg/kg.

A comparison of the content of the elements of the background zone with the content in the other zones of the park's soils is shown in Table 4.

As the data in Table 3 show, the excess content of chemical elements in the park zones in comparison with the background in the recreational area is not observed only in cobalt, chromium and manganese. Cadmium shows a slight excess, in the case of copper and nickel, the excess is 1.60-1.75 times higher, in lead and zinc, respectively, this excess increased by 2 and 3 times. In the settlement there is no excess in the case of cadmium and manganese, a slight excess is noted in cobalt and zinc. An excess of about 2-3 times can be noticed in chromium, lead and copper. The maximum exceedance of 9 times is noted for nickel. In the highway zone, a slight excess is observed in the case of cobalt and lead, in the case of manganese, the excess reaches 1.5, in the case of chromium – 1.8 times. The maximum excess of about 5 times is noted in the case of nickel. In three metals: copper, cadmium and zinc, the content increases about 3 times compared to the background. To assess the degree of soil contamination in the park, the values of the concentration factor (C_f) of heavy metals in the soils of the BSNNP were calculated by zones, which is shown in Fig. 1.

Calculations of the concentration coefficient (Table 4 and data from Fig. 1) show that its value does not exceed unity for the recreational area only for manganese, in the soil zone of the settlement for cadmium and manganese only, in the highway soil for all metals C_f>1.

The calculation results for assessing the degree of soil contamination in the park without and with consideration of the toxicity of chemical elements are shown in Tables 5 and 6, respectively.

The data in Table 5 show that the maximum value of Z_c = 15.3 shows the soil of the highway, in the settlement soil Z_c = 13.9 and the minimum value of 5.7 is noted in the soil of the recreational area. But even the maximum value (15.3) fits into the gradation of a low

Table 3. The concentration of mobile forms of heavy metals in the soils of the BSNNP by sites.

Heavy metals	TVL for mobile forms	Content, mg/kg			
		Natural	Recreational	Settlement	Highway
Cadmium	0.5*	0.058	0.070	0.053	0.176
Cobalt	5.0	0.241	0.246	0.267	0.280
Chrome	6.0	0.102	0.103	0.186	0.181
Copper	3.0	0.074	0.117	0.240	0.203
Manganese	140.0	98.880	50.780	73.920	151.94
Nickel	4.0	0.110	0.193	1.025	0.568
Lead	40-6.0	0.386	0.811	0.880	0.429
Zinc	23.0	2.307	6.896	2.669	7.330

Table 4. Excess of the content of chemical elements in the park areas in comparison with the background.

Heavy metals	Excess element content by zones		
	Recreational	Settlement	Highway
Cadmium	0.12	–	3.03
Cobalt	–	1.1	1.14
Chrome	–	1.82	1.77
Copper	1.58	3.24	2.74
Manganese	–	–	1.53
Nickel	1.75	9.3	5.16
Lead	2.10	2.3	1.11
Cinc	2.99	1.16	3.17

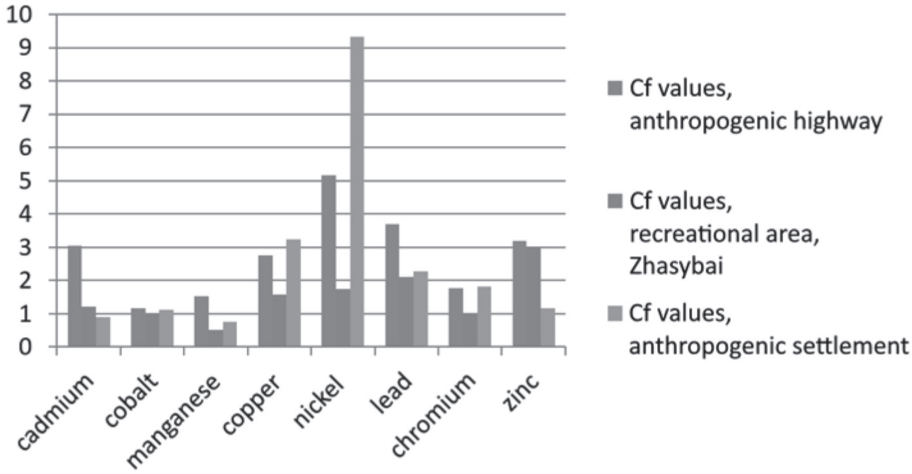

Fig. 1. Diagram showing the excess of C_f in BSNNP soils by zones.

level of pollution (compare with the data in Table 3).

However, this is not the case when calculating the total pollution considering the toxicity. As shown in Table 5, the maximum value of Z_c, taking into account toxicity, is found in the highway zone (12.9), which is contaminated with metals of hazard class 1, also this zone is contaminated with elements of hazard class 2 and 3. The recreational area and the settlement area are contaminated with metals of hazard class 1 and 2. The values of the Z_c indicators for the recreational area are 9.8, for the settlement – 16.6. And then only in the recreational area, the value of Z_c falls within the limits of a low level of pollution (9.8). In the case of anthropogenic settlement and highways, the Z_c value already passes into the limits of the average level of pollution (16.6 and 21.5) (Table 3).

So, according to the study of the impact of the concentration of heavy metals (HM) in the soils of the BSNNP, the following may be stated. The background content of heavy metals in BSNNP was taken as their content in the natural zone, which is considered far from the anthropogenic zone. The data in Table 3 show that in the soils of all the studied areas of the BSNNP forest the highest concentration in the series of studied metals is shown by manganese and it ranges from 51-152 mg/kg. The maximum value in the park's soil of about 152 mg/kg shows the content in the soil along the highway, and it is higher than the TLV by 11.9 mg/kg. In second place is zinc and its content is in the range of 2.3-7.3 mg/kg. As the data in Table 3 show, the excess content of chemical elements in the park zones in comparison with the background in the recreational area is not observed only in cobalt, chromium and manganese. Cadmium shows a slight excess, in the case of copper and nickel, the excess is 1.60-1.75 times. For lead and zinc, respectively, this excess increased by 2 and 3 times.

In the settlement there is no excess in the case of cadmium and manganese, a slight excess is noted in cobalt and zinc. An excess of about 2-3 times can be noticed in chromium, lead and copper. The maximum exceedance of 9 times is noted for nickel. In the highway zone, a slight excess is observed in the case of cobalt and lead, in the case of manganese, the excess reaches 1.5, in the case of chromium – 1.8 times. The maximum excess of about 5 times is noted in the case

Table 5. Values of indicators of total soil pollution without considering the toxicity.

The value of Z_c	Zone		
	Recreational area	Settlement	Highway
	5.66	13.926	15.287

of nickel. In three metals: copper, cadmium and zinc, the content increases about 3 times compared to the background. The maximum value of Z_c = 15.3 is shown in the soil of the highway, in the soil of the settlement Z_c = 13.9 and the minimum value of 5.7 is noted in the soil of the recreational area (without taking into account the toxicity of metals). However, this is not the case when calculating the total pollution taking into account toxicity. The maximum Z_c value with respect to toxicity is found in the highway zone (12.9), which is contaminated with hazard class 1 metals, this zone is also contaminated with hazard class 2 and 3 elements. The recreational area and the settlement area are contaminated with metals of hazard class 1 and 2. The values of the Z_c indicators for the recreational area are 9.8, for the settlement – 16.6. And then only in the recreational area, the value of Z_c falls within the limits of a low level of pollution (9.8). In the case of anthropogenic settlement and highways, the Z_c value already within the limits of the average level of pollution (16.6 and 21.5) (Table 3).

Consequently, the concentrations of HMs in the soils of the BSNNP showed that manganese and zinc show the highest concentration among the studied metals. According to the gradation of pollution in the BSNNP (both without and taking into account toxicity) Z_c<16, therefore, soil pollution in these territories can be attributed to low-level pollution, with the exception of anthropogenic zones of the settlement and the BSNNP highway, where the Z_c value is already within the limits of the average level of pollution (16.6 and 21.5). Earlier, our research revealed that 35 species belonging to 21 families were identified in the mountain forests of the Bayanaul SNNP. The largest family in terms of the number of species represented is *Asteraceae* – 20%, followed by *Rosaceae* – 11.4 %. Followed by *Plantaginaceae* – 8.5 %, species of the *Poaceae, Lamiaceae, Fabaceae* families make up 17.1 % [2]. The results of the study on anthropogenic sites showed that the leading families of the forest flora of the national park are *Asteraceae, Rosaceae, Roaceae, Fabaceae, Plantaginaceae, Lamiaceae* (Fig. 2).

A significant part of the forest flora of the national park is made up of forest-steppe plants of the natural area: *Veronicas puria L.,* Male fern (*Dryopteris filix-mas (L.),* Narrow-leaved fireweed (*Chamaenerion angustifolium L.),* Sage flowers (*Salvia tesquicola).* The same percentage of the projective cover is occupied by wood small-reed or bushgrass *Calamagrostis epigejos (L.)* on a natural and anthropogenic soil areas. The remaining plant species on the anthropogenic site, located next to the highway, are extremely unevenly distributed or occur in single specimens (Fig. 2). This indicates a significant impact on the plant community of anthropogenic factors, both mechanical and, probably, pollutants associated with the increase in atmospheric pollution due to the operation of the highway. The species diversity of natural ecotones is much higher than in anthropogenic areas. The analysis of the ecological spectrum of the flora showed that in the anthropogenic

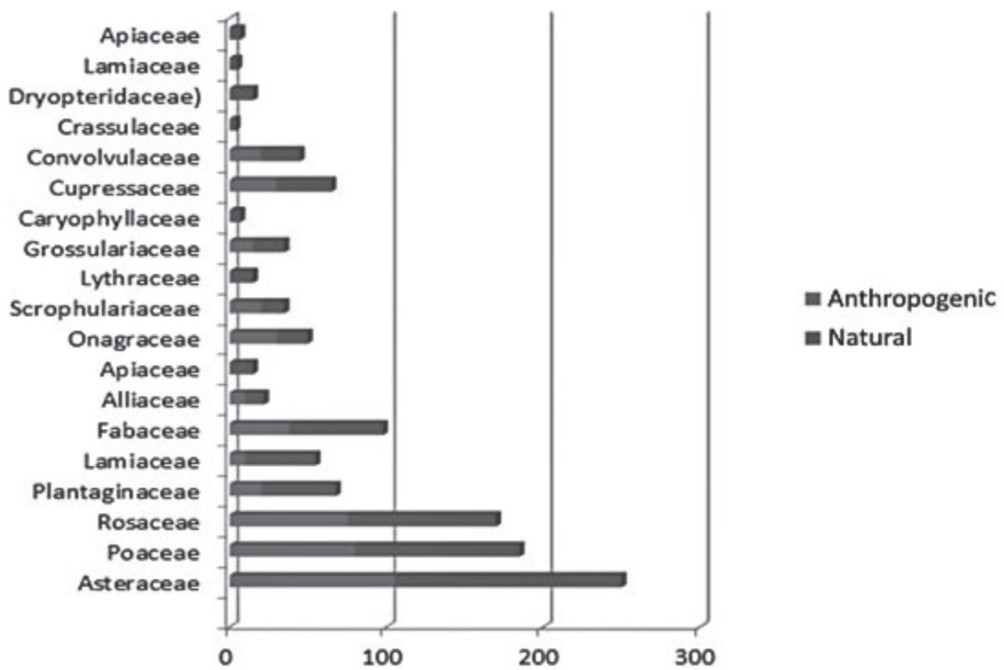

Fig. 2. Projective covering of herbaceous plants of common species in anthropogenic and natural sites of BSNNP.

Table 6. Values of indicators of total pollution, taking into account toxicity.

Toxicity class	The Z_c value for heavy metals by toxicity		
	Zones		
	Recreational area	Settlement	Highway
1	7.444	4.153	12.869
2	2.364	12.491	7.841
3	-	-	0.766
Total	9.808	16.644	21.476

Table 7. The ratio of plants of different ecological groups at the research sites %.

Name	Mesophytes	Xerophytes	Xeromesophytes
BSNNP – Anthropogenic sites	36	16	12
BSNNP – Natural site	27	20	51

areas of the Bayanaul forest there is a predominance of species belonging to mesophytes, xeromesophytes (Table 7).

Thus, the anthropogenic impact associated with the increase in atmospheric pollution due to the functioning of the highway, the recreational area and the settlement leads to a violation of the floral composition, a decrease in the projective coverage and the percentage of xerophytes, xeromesophytes in the sites of the Bayanaul SNNP. The presence of a large number of weed species *Artemisia campestris L., Atriplex patula L., Sonchus arvensis L* was established, which indicates an increase in the processes of synatropisation of the vegetation cover and disturbance of the environment of the studied territory. The basis for maintaining the stability of phytocenoses is the cycle of generations of individuals in the population. The termination of such a cycle inevitably leads to the disappearance of the corresponding spatial-population system. The most easily defined sign of stable cenosis is the completeness of the age composition of edificatory wood [2, 13]. The age structure reflects the rate of population renewal and the interaction of age groups with the external environment. The age structure and special features of the age structure allow to identify patterns of plantings development and devise ways to renew and increase the productivity of stands [14].

All age groups of stands are represented in the age structure of pine stands in the Bayanaul SNNP. Thus, young trees under 30 years old accounted for 20%, average-aged 21%, while old trees from 61 to 90 years old (29%) predominate, which indicates the relative youth of pine plantations. The maximum age of Scots pine on the territory of the BSNNP is 161 years. The ratio of age groups in the structure of the population of Scots pine in the studied forest ecosystems characterises its ability to reproduce and survive. When assessing the impact of anthropogenic factors on the age structure of trees, it was found that the average age of trees on anthropogenic sites in the Bayanaul forest is 90 years with an average height of 18.3 m and a diameter of 126.5 m. The average height and average diameter of trees in anthropogenic areas gradually rise with increasing age in all the studied areas. However, at the same age of trees in areas under different growing conditions, the average height and diameter of the trunk of trees are not the same, as well as in natural areas. For example, in the Bayanaul forest at an age of stands of 60, the height of the stands is 12.33 m, which is apparently due to the growth of forests on mountain soils. In the BSNNP, the population of pine forests is of a regressive type, where old-age trees mainly predominate, which make up 33%, indicating the processes of degradation.

The results of the study showed that the sanitary condition of pine forests growing in anthropogenic areas of the BSNNP has various stages of recreational digression. It was discovered that with an increase in anthropogenic pressure, the number of trees of the "healthy" category is observed in BSNNP trees – 3% and 5% – stage II and 2% –stage III digression, respectively. The amount of deadwood of the current and previous years ranges from 1 to 5%, where more than V and VI stages of tree digression is found in BSNNP. According to the literature data, it is known that in intact pine forests the proportion of withered and dry trees does not exceed 1%, in moderately disturbed from 2 to 5% and severely disturbed more than 10% [10]. Our studies have shown that dry trees accounted for the largest share in anthropogenic sites in the BSNNP. Consequently, an increase in withered and dried trees is an indicator of recreational load. Along with signs of recreation, such as an increase in withered and dry trees, mechanical damage in the form of bare roots as the result of soil failure and felled trees were observed. Thus, in the recreational area, the number of trees with bare roots increased from

0 to 69%, and those cut down from 3 to 19%. The sanitary condition of the pine forests of the BSNNP has various stages of recreational digression. The main factor in the weakening of forests and their drying up is anthropogenic factors, the negative impact of which is steadily increasing. As a result, the productivity of forests and their ability to self-heal decreases. Consequently, the pine forests of the BSNNP can be attributed to moderately disturbed forests, as a result of which there is a decrease in resistance to anthropogenic factors and human economic impact.

The dynamics of the natural renewal of pine forests reflects the success of the restoration of forest ecosystems. By the presence and quality of seedlings and undergrowth, it is possible to judge the course and possibility of reproduction of forest resources in a natural way. Identification of the number of renewals is a necessary condition for the existence of forests. Thus, the number of renewals in the Bayanaul forest, on average, amounted to 443 pcs/ha of undergrowth and 123 pcs/ha of seedlings. In the Bayanaul forest, there is a lack of seedlings in most areas, since unfavourable growing conditions are noted in the stony and rocky forests: loamy-crushed stone soil along the crevices, which is characterised by a dry moisture regime. In the herbaceous and shrub forests, the lack of regeneration is due to the high projective cover of herbaceous plants and the presence of a shrub layer (black cotoneaster (*Cotoneaster melanocarpa* Lodd), scalloped spirea (*Spiraea crenata* L.*)*, savin juniper (*Juniperus sabina* L.), Scots rose (*Rosa spinosissima* L.*).* Consequently, in the Bayanaul forest, there is practically no renewal (seedlings), which indicates an unsatisfactory restoration of forest stands. The results of the study showed that the generalised tree-ring chronology for the Bayanaul SNNP has a size range from 1858 to 2018, which is 161 years for a natural site, and for anthropogenic sites from 1924 to 2018, which is 95 years (Fig. 3).

Fig. 3 shows that there is a stable annual growth of Scots pine wood in the studied area. It should be noted that in some years the growth of pine trees differed from the total growth (Fig. 2). For example, there was a low increase of 0.26 mm. in 1937 in the anthropogenic area. There was also a low increase in stands of Scots pine from 2000 to 2018 both on the natural site and on the anthropogenic site, which averages 0.69 mm. The increase in the growth of the annual ring on the anthropogenic site near the road is apparently associated with the competition of trees [15].

Thus, on the natural site, the competition is, on average, 0.55 mm, and on the anthropogenic site, 0.4 mm. On an anthropogenic site, trees grow singly, where the density is lower than on a natural site of trees. It was found that the less competition there is between trees, the greater the growth of the trees. Consequently, the results showed that in the studied territories of the BSNNP, the effects of anthropogenic factors on the quantitative and qualitative indicators of the radial growth of the annual ring of Scots pine have a negative impact and leads to a decrease in the average values of the annual growth of pine wood. In the BSNNP over the past 50 years, the average annual growth of pine trees has also changed. Dendrochronology from 1969 to 2018 revealed that the annual growth on average in the BSNNP changed insignificantly. The annual growth and the amplitude of fluctuations varied from 1.1 to 1.1 mm in the natural area and from 1.4 to 1.1 mm, which indicates an slight effect of atmospheric pollution on pine growth (Fig. 4).

For the studied territory, the results of comparing anthropogenic and natural sites were obtained for the first time, which allows to assess the variability of annual growth of (*Pinus sylvestris L.)* on the studied natural sites. The obtained factual material will form the basis for identifying regional features of annual growth, will serve as a source material for multifactorial analysis, forecasting and reconstruction of the state of forest ecosystems and the climate of the North-East of Kazakhstan under the influence of natural and anthropogenic factors.

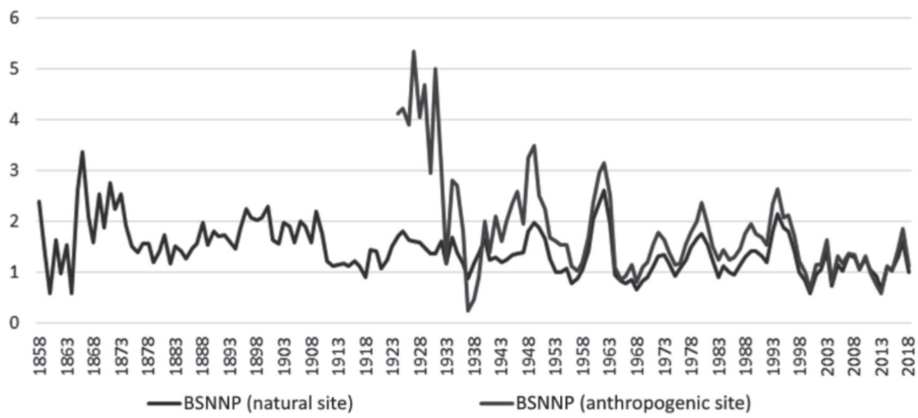

Fig. 3. Comparison of the natural and anthropogenic site of the BSNNP. Generalised tree-ring chronology for Scots pine (*Pinus sylvestris* L.) in the studied territory of the BSNNP.

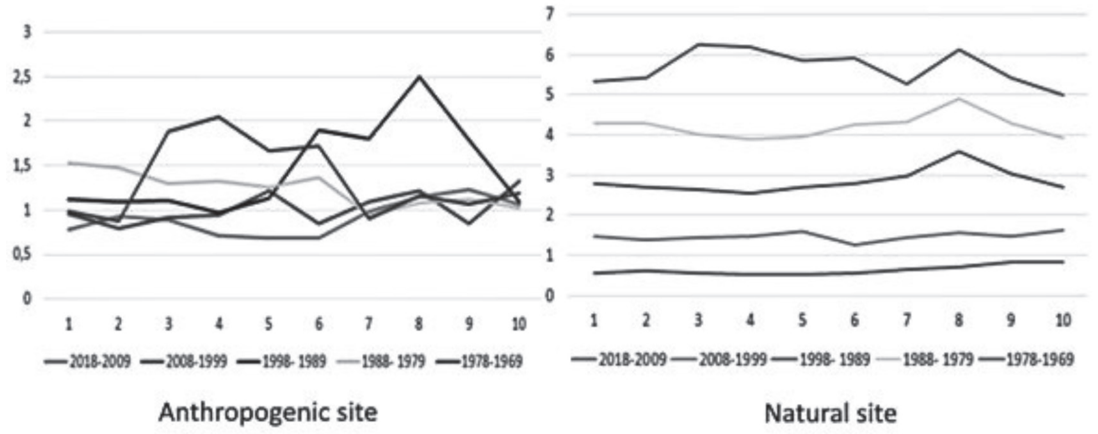

Fig. 4. Annual growth of Scots pine in the studied territory of the BSNNP over the past 10-50 years on an anthropogenic and natural site.

According to the results of our research, 4 arboretums of Scots pine (*Pinus sylvestris* L.) were built in natural and anthropogenic stands of BSNNP. Statistical analysis of dendrochronological series allowed us to estimate the spatio-temporal changes in the annual growth of wood in the study regions. In the studied areas over the past 50 years, to a greater extent exposed to anthropogenic impact, there is a decrease in the amplitude of growth fluctuations, especially with vehicle pollution, the frequency and cyclicity of growth of Scots pine wood is disturbed, which negatively affects the quality of wood in general and the stability of the biocenosis. The presence of reference dendroscales is the basis for monitoring the state of pine stands in the North-East of Kazakhstan. Forests, as a rule, are resistant to natural disturbances within certain limits and have the properties to recover after violations [16]. Degradation and restoration can occur at different levels of the ecosystem organisation. Thus, at the level of species composition, as a result of excessive violations, biodiversity decreases, which leads to the replacement of natural phytocenoses [17]. At the level of forest types, violations lead to a decrease in the areas occupied by native stands and an increase in the areas of forests that are at a certain stage of succession [18-20]. In our study, we selected criteria for forest degradation based on the relationship with the main causes of forest ecosystem degradation.

Conclusions

The results of the study showed that the Bayanaul Park is characterised by higher biodiversity and high projective coverage, but, despite the weak disturbance of vegetation, insufficient renewal of pine plantations in the immediate vicinity of the highway was revealed. These types of trees are likely to be degraded as a result of anthropogenic impact, as well as due to the lack of seedlings in the immediate vicinity of the highway, villages and recreational area.

The results of the research revealed that old-age trees and young trees predominate in the Bayanaul SNNP, which indicates a weak process of reforestation in the past periods. Stocks of overmature age groups are typical for unsustainable felling. The forest is aging, its productivity is decreasing, the incidence of old trees is increasing, there is a decrease in the growth of the annual ring of Scots pine wood, including over the past 50 years. The vegetation cover of the studied region also experiences significant anthropogenic loads.

Based on the conducted research, it is necessary to develop a forest management program taking into account the extreme growing conditions of the intrazonal steppe forests of Kazakhstan. Monitoring of the BSNNP is necessary to ensure the needs of the executive authorities of state power of Kazakhstan for prompt and reliable information about changes in protected natural complexes and objects for making scientifically based and effective management decisions, as well as ensuring the right of citizens and legal entities to information about the state of the environment.

Acknowledgments

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Conflict of Interest

The authors declare no conflict of interest.

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