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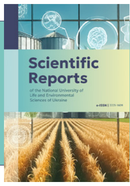

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Retrospective analysis of the dynamics of spruce drying in different forest conditions Gorgan

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Abstract. The study aimed to assess changes in the intensity of spruce drying in different forest types and at different altitudes, addressing the time factor. The research was conducted in the central part of the Gorgan Mountain range in its foothills (the Bystrytsia Solotvynska river basin) on an altitude-typological profile. The degrees of decomposition of dead wood were characterised to determine the following types of trends in the spruce drying process in different types of forests and tree species composition: fading with a decrease in intensity over time; weakly expressed with significant fluctuations in drying out in individual years; intense with an annual increase in the phenomenon. The duration and dynamics of these trends for different forest vegetation conditions were noted. On the example of three forestries, the annual dynamics of spruce drying areas in the period from 2016 to 2024 for the spectrum of vertical vegetation belts available in the Gorgany was presented in the following sequence: foothill fir-oak, mountain beech-fir, beech-fir-spruce and pure spruce forests. The results of the statistical analysis indicate that spruce drying processes are multidirectional, depending on the gypsometric levels of the relief and the associated altitudinal zonation. The study determined that in foothill fir-oak forests, the intensity of spruce drying decreases. This pattern was somewhat less pronounced in the lower mountainous zone of beech and fir forests (500-600 m). In the altitudinal range of 650-1000 m (the upper part of the beech-fir belt and the lower part of beech-fir-spruce forests), the intensification of spruce drying is notable. The study demonstrated that at altitudes above 1000 m, patterns in the drying of spruce forests are not pronounced, as this phenomenon is sporadic. The practical significance of the research results is reduced to their use in differentiated measures to enhance the sustainability of stands in different altitudinal zones

Keywords: altitudinal zones; forest types; stand composition; dead wood; empirical dependencies

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Introduction

One of the biggest challenges for forestry in the Ukrainian Carpathians is the intensification of spruce drying out due to climate warming. The widespread occurrence of this phenomenon creates critical situations regarding the loss of valuable timber and a decrease in the sustainability and protective role of forests in the ecologically unstable mountainous and foothill conditions of the region. The drying out of spruce forests in the Ukrainian Carpathians has been considered a natural disaster, with the main causes being a decrease in its resilience and weakening of stands as a result of increasing above-zero temperatures and past forestry activities. This process is especially relevant for the Gorgan Mountain range, where European spruce (*Picea abies* (L.) H. Karst.) accounts for approximately 70% of the forest stock. The decline covers approximately 13% of the forest area and 39% of the spruce forests, and in some forestries with a significant distribution of this species, 12-18% and 53-85%, respectively (Zeinalian, 2021). According to the research by Y.S. Shparyk & T.V. Parpan (2020), in wet conditions of Ukrainian Carpathian spruce forest, the average drying rate of medieval and medium-sized stands with a spruce proportion of 6-7 units was 3%, for wet beech-fir forest – 1%, and for wet beech-spruce forest – 2% per year. The identified drying trends were used to compile a calculation framework for the area and stock of spruce for the next 20 years. The forecast until 2040 showed that the average loss of spruce area in spruce forest types of the Ukrainian Carpathians will be 28%, with a decrease in the number of trees in the first tier and the accumulation of significant reserves of dead spruce wood – up to 300 m^3/ha.

Given the widespread distribution of spruce stands in Central Europe, the research by J. Krejza *et al.* (2021), which assessed their growth under climate change, is noteworthy. This publication presents data demonstrating that the most intensive drying was observed in the experimental plots located at an altitude of ≈ 600 m above sea level. E. Bowditch *et al.* (2021) and R. Bace *et al.* (2023) provided evidence that the existing climatic conditions in the Central European region are not suitable for growing European spruce at lower and middle altitudes, which should be accounted for when developing a new spruce forest growth management programme. The impact of forestry measures on the condition of spruce forests and the growth characteristics of natural spruce stands without forestry activities were studied by T. Hilmers *et al.* (2019).

The literature indicates that the processes of spruce forests drying out and their area are not the same for different forest vegetation conditions (Kramarets *et al.*, 2024), forest types and stands (Matusevych, 2022). However, the quantitative assessment of these changes is largely unexplored. First, this concerns their spatial and temporal dynamics due to the inherent variability of climate, relief and forest cover in the mountains.

The drying out of the Carpathian spruce forests, which started in the mid-1990s under the influence of global climate warming, continues to this day. Several scientific publications have been devoted to this problem, covering the factors, causes and spread of the phenomenon, the role of abiotic and silvicultural factors in its formation, forestry and environmental consequences, and proposals for strengthening forest resilience (Brodovych & Brodovych, 2023).

V.S. Oliinyk & A.M. Zeinalian (2020) studied the effect of thermal conditions on the drying of woody species, which was associated with the height of mountain slopes. The authors determined that with increasing altitude, the temperature regime changed, which directly affected the physiological state of trees. Altitude zonation affected microclimatic conditions that determined the spread and intensity of drying out. The results of the study showed that the height of the slopes was a factor that modified the manifestation of the harmful phenomenon since thermal stress in the highlands was significantly different from the conditions of the lowlands.

I. Shyshkanynets *et al.* (2021) addressed the change in the intensity of spruce drying depending on the time factor in different forest conditions. The authors noted that the dynamics of drying processes demonstrated a gradual deterioration of the trees due to the impact of climate change and biotic factors. Forest vegetation conditions, such as soil type, humidity and site exposure, were central in determining spruce resilience to adverse factors. The study highlighted the importance of long-term monitoring to understand these processes and develop adaptation measures for forest ecosystems.

Y. Shparyk *et al.* (2020) covered dead wood as an indicator of wood drying processes. The authors proved that the state of decomposition of dead wood can be used for a retrospective assessment of the time and nature of drying processes in the past. This approach was effective for making predictions on the state of forests, as information on wood decomposition could be integrated into models of forest ecosystem development. The study emphasised the importance of accounting for dead wood not only for analysing ecosystem processes but also for predicting their evolution.

In general, the current distribution and growth characteristics of spruce stands in different forest vegetation conditions of the Gorgan on a typological basis remain understudied. Factoring in the time factor when assessing changes in the intensity of spruce drying will make it possible to develop silvicultural programmes for the reproduction of native stands in the most common types of spruce forests in the study area.

The study was aimed at assessing changes in the intensity of spruce drying in different forest types and altitudinal zones depending on the time factor.

To achieve the research objective, the following tasks were defined: to analyse dead wood stocks and the degree of its decomposition in the main forest types; to assess the dynamics of annual areas of spruce forests in the altitudinal zones of foothill fir oaks, mountain beech-fir, beech-fir-spruce and spruce forests.

Materials and Methods

The study was conducted in three forestries of the Osmolodske Forestry branch in 2016-2024. The object of the study was spruce forests located in foothill fir-oak and mountain beech-fir, beech-fir-spruce and spruce forests at altitudes from 300 to 1400 metres above sea level. The study analysed the drying processes of spruce forests in different forest vegetation conditions typical for the Gorgan Mountains and their foothills. The study was conducted following the ethical standards set out in the Convention on Biological Diversity (1992) and the Convention on Trade in Endangered Species of Wild Fauna and Flora (1973).

The processes of spruce forests drying out were studied in two ways of retrospective analysis: 1) by the degree of decomposition of dead wood in five test plots in different forest types; 2) by the dynamics of annual allocation of spruce drying areas for sanitary felling in different altitude forest zones. These approaches were used to comprehensively assess the condition of spruce forests and establish the temporal patterns of their degradation.

The trial areas were laid out at relief heights of 300-900 m (SOU 02.02-37-476:2006, 2007), where spruce drying processes are most pronounced in mountainous conditions (Hudyma *et al.*, 2014; Oliinyk & Zeinalian, 2020). They are confined to the main forest types of the Gorgan; their stands are similar in age but differ in the proportion of spruce and wood stock. The deadwood and lying deadwood in the sample plots were counted according to generally accepted forest inventory methods. At the same time, A. Schuck *et al.* (2004) distinguished the stages of its decomposition – from fresh undecomposed to decayed state. Each of these stages allowed to establish the time limits of wood death: for Gorgan spruce forests, dead wood in the first stage of decomposition indicates that it was formed 2-3 years ago, the second – 5-10 years, the third – 10-15 and the fourth – 15-20 years ago (Shparyk & Parpan, 2020).

The annual dynamics of drying areas and their trend over time were studied on an altitudinal forestry profile in the Bystrytsia Solotvynska river basin, which covered three forestry units of the Osmolodske Forestry branch – Bohorodchany, Manyava and Hutyany – following the vertical differentiation of vegetation in the Ukrainian Carpathians (Stoyko, 2012; Zeinalian, 2021). These processes are consistently associated with foothill fir-oak forests, mountain beech-fir, beech-fir-spruce and partially spruce forests. Data on the drying out of spruce forests were collected and analysed based on departmental materials on the allocation of drying out areas for sanitary felling with their distribution by altitude zones and forest strips. The data on relief indicators and silvicultural and taxonomic features of the stands in the drying areas were borrowed from forest management materials. In total, more than 300 sites in the altitude range of 300-1400 m were analysed.

For high-altitude forest vegetation zones, the proportion of spruce forests, the coefficients of variation in drying out of the species over the years, and the regression equation for the dependence of its drying out on time were determined. The empirical formulas were calculated with pairwise correlation coefficients greater than 0.6 and a confidence level of more than three.

Results and Discussion

The analysis of materials on the accumulation and dynamics of dead wood on the experimental objects of high-altitude forestry profile (Table 1) shows the following features of this process.

Table 1. *Stocks and degrees of decomposition of dead wood in different forest conditions*

Characteristics of the research facilities	Height above sea, m				
	300	600	680	850	900
Silvicultural and taxation indicators stands					
Forest type	C_3-FirCo	D_3-Fb-FirSpr	C_3-Fb-FirSpr	C_3-Fb-FirSpr	C_3-Fb-FirSpr
Composition of the stand	6Spr3Sc1B+Fir,Co	5Fir3Spr1Sc1B	8Fir2Spr+Fb	6Spr3Fir1Fb+B	6Spr3Fir1B+Fb
Age, years	64	62	54	57	60
Completeness	0.7	1.0	0.7	0.9	1.1
Reserves, $m^3 \cdot ha^{-1}$	160	560	290	450	560
Stock of dead wood (dead and dead wood) *					
Total, $m^3 \cdot ha^{-1}$	144/134	83/70	73/29	144/92	104/101
By degree of decomposition:					
1	4/3	5/0	48/11	59/17	6/6
2	19/19	18/12	17/11	39/32	30/27
3	48/48	34/32	8/7	43/40	28/26
4	73/64	26/26	0/0	3/3	40/40
Trend drying spruces	pronounced 20-year decay	weak 20-year decay	weak 15-year increase	intensive growth 5-15 years ago	intensive growth 15-20 years ago

Note: Spr – European spruce; Fir – white fir; Sc – Scots pine; Cp – cedar pine; Fb – forest beech; Sy – sycamore; Co – common oak; B – hanging birch; * in the numerator – for the entire plantation, in the denominator – for spruce

Source: developed by the author

Firstly, reserves of dead wood depend on the proportion of spruce in the composition of stands. Thus, its increase from 2-3 units to 6 units contributes to a 2-4-fold increase in the volume of dead wood reserves. In mountainous conditions, they increase with the increase in gypsometric relief levels caused by an increase in the proportion of spruce forests (r = 0.83) and a slowdown in wood decomposition due to a vertical decrease in the maximum temperatures of the growing season (r = 0.96).

The dynamics of dead wood accumulation are different in certain forest vegetation conditions. Judging by the presence of the 3rd and 4th stages of its decomposition, which respectively characterise the age of its formation over 10-15 and 15-20 years, it is possible to assume that the impetus for the drying of the species was the extreme weather conditions of the late twentieth and early twenty-first centuries, namely the hot and extremely dry periods of active vegetation in 1995-2003. According to forest meteorological studies in the Gorgan spruce forests (Oliinyk & Zeinalian, 2020), these periods were characterised by minimal precipitation, which amounted to only 55% of the norm, and in some summer months even dropped to 9.5-18% of the norm.

In general, the analysis of the dead wood condition shows that in different forest vegetation of the foothill and mountainous conditions of the Gorgan during 2016-2024, the trend of spruce forests drying out is different. Its directions are as follows: 1) fading with a decrease in intensity; 2) weak expression with fluctuations over the years; 3) increase with an increase in the area of drying.

In the foothill subboreal forests, where intensive drying of spruce stands began in the second half of the 1990s, there was a downward trend in this process (Tkachuk & Zeynalian, 2023). This is related to the small proportion of spruce derivatives and intensive sanitary felling. To a certain extent, a similar drying trend is characteristic of the neighbouring lowland spruce forests. At higher hypsometric levels (700-900 m) in mixed fir and spruce forest types, the drying of the species intensified after 2003. It is characterised by growth with slope height and maximum development 5-20 years ago.

The above-mentioned dynamics of spruce forests drying out over time is confirmed by the data on the allocation for sanitary felling of 326 forest plots affected by this phenomenon in different altitude forest zones of the three forestries of the Osmolodske Forestry branch in 2016-2024 (Table 2).

Table 2. *Dynamics of spruce drying areas in different altitudinal zones*

Years	All forests	Foothill forests (350-500 m)	Mountainous conditions						
			beech and fir forests			beech-fir-spruce forests			For mountain forests
			500-650 m	650-800 m	for the entire belt	800-1000 m	> 1000 m	for the entire belt	
2016	156	82	25	7	32	39	4	43	75
2017	112	39	22	19	41	27	5	32	73
2018	100	44	12	15	25	28	2	30	55
2019	145	58	6	21	27	45	15	60	87
2020	91	34	2	34	36	21	0	21	57
2021	52	12	0	12	12	27	0	27	39
2022	205	36	45	52	98	62	10	72	170
2023	215	29	19	35	54	114	17	131	185
2024	187	34	36	54	90	64	0	64	154
Total %	1263 100	368 29.1	167 13.2	248 19.7	415 32.9	427 33.8	53 4.2	480 38.0	895 70.9

Source: developed by the author

For the foothill spruce forests of the foothills, the decrease in drying areas in the specified time interval is notable. In the range of mountain altitudes of 650-1000 m (upper zone of the beech-fir belt and lower zone of the beech-fir-spruce belt), the opposite trends are expressed – an increase in the intensity of drying out of the rock. In the transitional, lower-mountainous zone of beech-fir forests (500-650 m) and at high hypsometric levels of mixed and pure spruce forests (above 1000 m), no clearly defined patterns of drying changes are observed. Despite the vertical variability of these processes, the phenomenon of spruce drying intensification prevails in mountain forests in general.

Dominant partial drying increases from foothill fir-beech forests (300-500 m) to mountain beech-fir forests (500-800 m), and then decreases in beech-fir-spruce forests (800-1200 m) and becomes non-existent in the upper spruce belt (at 1300 m). Continuous drying is characterised by a small proportion and a slight increase in the average area with increasing altitude. These patterns are caused by two factors:

1) the growth from the foothills to the upper boundary of the lower mountain belt of areas of spruce forests that are intensively exposed to drying out;

2) the slowdown of these processes from 800 m above sea level is caused by changes in meteorological conditions. At this level, the temperate climate zone with July temperatures of +17, +19° moves to the lower temperature zone, where they are 2-3° lower, and even higher, in the cold zone with pure natural spruce forests, temperatures drop to 12° or less.

The area of partial drying increases from 1.8-2.8 ha at 300 m to 4 ha at 600-800 m and then decreases, disappearing at 1200-1300 m. Areas of continuous drying increase evenly from 300 m (0.6 ha) to 1300 m (1.9 ha). In general, plantations at altitudes of 400-900 m are most vulnerable to drying out. In this altitude range, 87% of the centres and 84% of the area of this harmful phenomenon are concentrated.

In quantitative terms, the dynamics of spruce drying are characterised by the following results of statistical processing of materials in the context of the altitudinal zonation of mountain forests. In the foothill fir-oak forests, the proportion of spruce derivatives and the coefficient of variation of their drying areas over the analysed years are the lowest in Gorgan and amount to 20% and 45%, respectively. Changes in annual drying (S, ha) in Bohorodchany forestry over time (A, annual indices; 11-19 years of the 21st century) are characterised by a reliable inverse regression equation of the following type:

$$S = 112 - 4.71 \cdot A \quad \text{at } r = -0.66 \pm 0.18, \qquad (1)$$

which shows that in 2016-2024, the area of spruce drying out decreased by three times. The data on the area of spruce forests in the Bohorodchany forestry and the annual regression coefficients show that, if current climatic conditions remain unchanged, in 2022-2032, the main areas of spruce forests will be covered by sanitary felling, minimising the area of this derivative species.

Specific trends in the drying out of spruce derivatives are observed in the lower mountain belt of beech-fir forests in the Maniava and Hutia forestries, which is adjacent to the foothill conditions. The proportion of spruce plantations varies with altitude from 18 to 38%, and the coefficient of variation of the drying area of the species ranges from 61-100%. In the strip of beech spruce forests (500-600 m) adjacent to the foothill conditions, the spruce stands in the analysed years had a certain tendency to decrease in drying out ($r = -0.50$). The dependence of the species drying on the time factor is weak ($r = 0.28$) for the entire lower part of this belt at altitudes of 500-650 m. Only in the upper part of the belt (650-800 m) with 38 % spruce, there is a clear dependence of the intensification of rock drying on changes in the time factor:

$$S = 6.9 \cdot A - 50 \quad \text{at } r = 0.80 \pm 0.12. \qquad (2)$$

Such patterns of drying out of spruce derivatives in different altitudinal bands of beech spruce forests determine a positive trend towards a general belt-wide increase in this process, the empirical formula of which is as follows:

$$S = 6.7 \cdot A - 54 \quad \text{at } r = 0.62 \pm 0.21. \qquad (3)$$

It indicates that the area of drying out quadrupled between 2016 and 2024. The patterns of drying of derivative and native spruce forests are different in the high-altitude zones of beech-fir-spruce and pure spruce forests (800-1400 m). In these two forestries, the share is 57 and 85%, respectively. The belt of mixed spruce forests (800-1000 m) is characterised by a relatively small coefficient of variation of drying areas – about 59 % and their reliable positive dependence on the time factor:

$$S = 6.9 \cdot A - 56 \quad \text{at } r = 0.64 \pm 0.19. \qquad (4)$$

In this altitudinal range, the growth of spruce drying areas is similar to that of the beech spruce belt. At higher hypsometric levels (>1000 m asl), the coefficient of variation of drying areas by year is quite variable (≈ 104%), and their relationship with time is extremely low ($r = 0.15$). In certain years, this process is insignificant or even absent (Table 2). This is caused by significant relief heights with a corresponding decrease in air temperature and an increase in precipitation, which prevents the rock from drying out. In general, natural spruce forests at altitudes of 800-1400 m are characterised by a general tendency to dry out over time ($r = 0.58 \pm 0.22$), but it is not sufficiently expressed in quantitative terms due to the influence of relief and meteorological factors.

In mountainous conditions, the current intensification of spruce drying is most clearly manifested at altitudes of 650-1000 m (upper strip of beech spruce forests and lower part of mixed spruce forests). This pattern is reinforced by drying tendencies at other altitudes, and therefore the dependence of increased drying of the species dominates in mountain spruce forests (500-1400 m) at the present stage of climate warming. It is expressed by the following equation:

$$S = 13.9 \cdot A - 109 \quad \text{at } r = 0.70 \pm 0.17. \qquad (5)$$

Due to the different vectors of spruce drying in foothills and mountainous conditions, there is no general picture of this process in the region over time ($r = 0.45 \pm 0.27$). The analysis of the forest fund of the Manyava and Hutia forestries and the empirical dependence (5) suggests that under current climatic conditions, the main areas of spruce forests may be covered by sanitary felling in the next 7-8 years due to the drying out process.

Numerous studies revealed the influence of various environmental factors that can cause spruce forest degradation and drying out, particularly in mountainous conditions. Climatic and edaphic conditions have an impact on the specificity and intensity of spruce drying processes. To prevent spruce dieback, it is necessary to develop systems of forest protection measures that consider natural conditions and regional peculiarities of forest management.

According to European scientists, namely E. Gordeeva *et al.* (2022), the processes of spruce drying are observed in both native and derivative stands, but the situation in derivative spruce stands is currently more critical. Other researchers H. Spiecker & H.-P. Kahle (2023) noted that dieback processes are present in spruce stands of different ages but are most pronounced in pure medieval monocultures and older stands, as well as in sparse stands that have emerged on the site of natural oak and rock oak groves. V. Lavnyy & O. Pelyukh (2019) determined that the largest areas of spruce forests are concentrated in Ivano-Frankivsk region – 47.8% of the total area of spruce forests. Among the forest types, spruce-fir forests are most often found in wet spruce-beech successional forests. The authors also noted a decrease in the biotic and abiotic stability of spruce derivative stands.

The relationship between silvicultural and climatic factors and their impact on the sanitary condition of spruce stands was studied by H. Hrynyk *et al.* (2010). The analysis of the impact of climate change on the sanitary condition of spruce stands in the Ukrainian Carpathians was studied by H. Hrynyk & O. Hrynyk (2022). Due to changing climatic conditions in European countries, spruce forests are weakening, their sanitary condition is deteriorating, and plantations are drying out over large areas (Vyshnevskyi & Donich, 2021).

As spruce forests decline, the carbon storage of wood decreases and the amount of carbon released into the atmosphere during the decomposition of dead wood increases. Climate change has affected the condition and productivity of forest ecosystems, including mountain spruce monocultures, which were created in the 19th century in Europe and the Carpathians to produce ripe timber quickly – as a result of climate change, they began to dry out en masse. The most intense drying affected the spruce forests created on the site of fir and beech forests (Tkachuk & Zeynalian, 2023).

C. Yue *et al.* (2023) believe that in the second half of the twenty-first century, forest conditions will deteriorate further. It is expected that there will be even less precipitation during the growing season, and droughts will be more frequent and longer. Such climate change will contribute to an even greater spread of forest drying. This will result in significant changes in the species composition of forests. A. Taccoen *et al.* (2019, 2022) investigated the impact of climate stresses and dry periods on spruce drying in the Vosges and Ardennes, using remote sensing to monitor forest change.

The intensive die-off of spruce forests can be influenced by their age. According to L.M. Beley *et al.* (2022), the massive decline of mono-dominant dark coniferous forests is a normal phenomenon in the process of their age development. First of all, these processes are manifested in stands that have reached the age of old age for this species under certain conditions (Synek *et al.*, 2020).

The dominant feature of the distribution of forest vegetation in mountainous conditions is the altitude zonation, according to which the plantations are divided into zones: foothill oak forests (100-220 m asl, pure oak, beech-oak stands), beech forests (300-1450 m asl, pure beech, fir-beech, fir-fir-beech stands), spruce forests (700-1450 m asl, pure spruce, beech-fir, fir-spruce, beech-fir-spruce-spruce stands), subalpine belt (1300-1500 (1800) m asl, coniferous and deciduous shrubs), alpine belt (above 1800 m asl), which is primarily due to the climatic conditions of the mountainous terrain (Matusevych, 2022). In the context of modern climate change, which is accompanied by a global increase in air temperature, forest plantations are forced to adapt to new conditions. Therefore, identifying the current limits of spruce plantations and comparing them with the previously established ones will be used to assess the dynamics of the high-altitude distribution of European spruce stands. Therefore, spruce stands were grouped by altitude within the study area, the main silvicultural and taxation indicators, and dead wood stock.

To prevent the drying out of spruce forests and the formation of stable indigenous stands, a set of forest health measures (various types of felling, monitoring and protection of the forest, and reforestation) should be conducted, primarily in a timely manner: in mountainous conditions – up to the altitude range of 450-900 m above sea level, mainly on the southern slopes, as well as on all steep slopes with stony soils, regardless of their exposure; in foothill conditions – in forest areas adjacent to treeless lands. To prevent spruce stands from drying out, attention should be devoted to plantations with a spruce proportion of more than 3-5 units, 35-60 years old and with a fullness of 0.6-0.8, as they are most prone to drying out. Foothill sub-alpine conditions are not suitable for growing spruce derivatives, while lower mountain spruce forests are more promising. The best conditions for the formation of spruce forests are observed in spruce forest types, regardless of forest management systems.

Conclusions

Based on comprehensive silvicultural studies for different forest vegetation conditions, the stability of spruce forests in the Gorgan Mountains is assessed. The altitude-belt and silvicultural-taxation features of spruce forests drying out, their influence on structural changes in plantations and the dynamics of dead wood formation in them are revealed. The silvicultural condition of such stands and the processes of natural regeneration are highlighted. The leading abiotic factor of spruce drying is the relief height, which determines the dependence of these processes on mixed oak, fir and beech forest types in the altitude range of 350-1150 m above sea level. Plantations at altitudes up to 900 m are most vulnerable. At higher levels (spruce forest belt), these phenomena are insignificant. A retrospective analysis of the accumulation of dead wood in drying spruce forests shows that its reserves depend on the proportion of spruce in the stand composition and the height of the mountainous terrain, and the state of its decomposition indicates the subsequent trends in the drying of the species: 1) attenuation; 2) weak expression; 3) intensification. They have altitude-belt patterns.

In the fir subboreal forests of the foothills, the intensive drying of spruce derivatives that occurred at the turn of the twentieth and twenty-first centuries has been replaced by processes of slowing down this phenomenon. To a lesser extent, similar changes in spruce drying are characteristic of the neighbouring lowland strip of beech-fir forests. In the altitude range of 650-1000 m (the upper band of beech-fir forests and the lower part of the belt of beech-fir-spruce forests), processes of intensification of the species drying are observed. At altitudes above 1000 m, the dependence of spruce drying on time is insignificant.

Estimates show that if current climatic conditions remain unchanged, with the inherent drying out of spruce forests, in the next 8-10 years, sanitary felling will have to cover the main areas of spruce forests in the altitude range of 300-1000 m above sea level.

Spruce cultivation is not very promising in foothill spruce sub-forests. In lowland fir forests, silvicultural measures can control spruce drying out, reducing the high competitiveness of fir. In mountain-mixed spruce forests, properly implemented silvicultural measures contribute to the formation of indigenous highly productive spruce stands. In the absence of harvesting, spruce retains its position in the upper tier, while fir and beech spread in the subordinate tiers. In sub-arid conditions, native spruce stands of low productivity are formed. In general, spruce retains its viability in spruce forest types under different management systems.

In different forest vegetation conditions, the drying out of spruce forests in time is ambiguous. In foothill subboreal forests, it was highest in 2000-2010, after which it gradually decreased. Similar dynamics are typical for spruce in lowland fir forests. In mountain spruce forests, there are no clear patterns of spruce drying out over time. In spruce forests, this phenomenon intensified in 2005-2010 and continues to this day on steep slopes of southern exposures with gravelly soils. In sub-boreal conditions, spruce drying is similar to the process in birch forests.

Further research could identify the key factors that influenced the change in the intensity of the process, including climatic conditions, anthropogenic impact, changes in soil properties and stand structure.

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Conflict of Interest

None.

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Ретроспективний аналіз динаміки всихання ялинників у різних лісорослинних умовах Ґорган

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Анотація. Метою роботи було оцінити зміни в інтенсивності всихання ялинників у різних типах лісу та на різних висотах з урахуванням фактора часу. Дослідження проводилися у центральній частині гірського масиву Ґорган із його передгір'ям (басейн річки Бистриця Солотвинська) на висотно-типологічному профілі. Охарактеризовано ступені розкладу мертвої деревини, за якими визначено наступні види трендів процесу всихання ялини у різних типах лісу та породним складом деревостанів: затухаючий із зменшенням інтенсивності по мірі плину часу; слабко виражений із значним коливанням всихання по окремих роках; інтенсивний із щорічним збільшенням площ явища. Відзначено тривалість та динаміку цих трендів для різних лісорослинних умов. На прикладі трьох лісництв висвітлена річна динаміка площ всихання ялини у період з 2016 по 2024 роки для наявного у Ґорганах спектру вертикальних рослинних поясів у такій послідовності: передгірних ялицево-дубових, гірських буково-ялицевих, буково-ялицево-ялинових і чистих ялинових лісів. Результати статистичного аналізу свідчать про різновекторність процесів всихання ялини залежно від гіпсометричних рівнів рельєфу і пов'язаної з ним висотної поясності. Виявлено, що у передгірних ялицево-дубових лісах інтенсивність всихання ялини затухає. Дещо слабше ця закономірність виражена у нижньогірській смузі буково-ялицевих лісів (500-600 м н. р. м.). У висотному діапазоні 650-1000 м (верхня смуга буково-ялицевого поясу і нижня частина буково-ялицево-ялинових лісів) досить чітко виражена інтенсифікація всихання ялини. Наведено дані, що на висоті більше 1000 м н. р. м. закономірності у всиханні ялинників не виражені, оскільки це явище тут спорадичне. Практична значущість результатів досліджень зводиться до їх використання у диференційованих заходах щодо посилення стійкості деревостанів у різних висотних поясах

Ключові слова: висотні пояси; типи лісу; склад деревостанів; мертва деревина; емпіричні залежності