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STRONG WINDS AND WINDTHROWS IN THE FORESTS OF THE UKRAINIAN CARPATHIANS



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Using data from 16 meteorological stations, the frequency and intensity of strong winds (≥ 20 m/s) in the Ukrainian Carpathians have been analysed. 6,633 events of strong wind were recorded in this region, 60 per cent of them at the mountain meteostations Pozhezhevs'ka and Plaj. The number of strong winds at each station varied greatly from one year to another. In 1996 an annual maximum of 52 strong winds at one station (Pozhezhevs'ka mountain) was recorded. In general, frequency of the strong winds fluctuated and showed cyclical character. 60 per cent of the strong winds occurred between October and March. 55 percent of the analysed strong winds showed maximum wind speeds between 20.0 and 24.9 m/s. There were a total of 413 strong wind events (6.2 %) with the wind speeds of 40 m/s or more. Winter storms usually lasted longer than summer storms. Analysed was the literature regarding the factors affecting the extent of windthrows. Also, investigated was the influence of the stands composition, their age, average height, average diameter, site class and stand density on the volume of windthrows in the Ukrainian Carpathians. In general, the windthrows in the region under investigation have been only of local character. The volume of the windthrow timber made up on the average 238 m³ per ha. The amount of windthrows changes considerably from year to year. The most frequent forest windthrows were observed in spruce stands. This species made up 72 per cent of the total volume of the fallen trees. The share of silver fir made up 13 per cent of the fallen timber while the share of beech amounted to 12 per cent. Other species made up only 3 per cent of the fallen trees. The windthrows damaged largely the middle-density stands aged 71 to 90 years with the average height ranging from 26 to 30 m. The ways and methods of mitigating the wind-induced damage to forest of the Ukrainian Carpathians are indicated.

Keywords: forest damage; Ukrainian Carpathians; strong winds; windthrows; forestry.

Introduction

Intensive storms are, probably, the most important natural hazard for forestry. In 1990 and 1999, for example, severe cyclones caused extensive windthrow all over Central Europe. More than 300 million m³ of timber was blown down or broken by gales which originated in the cyclones "Vivian" and "Wiebke" in 1990 as well as "Lothar" in 1999 (Lavnyy & Lässig, 2001).

Like in Central Europe (Krapfenbauer und Holtermann, 2000), many foresters and scientists in Ukraine apprehend a further increase of storms in the Ukrainian Carpathians, in connection with the global increase of mean temperature. They fear that severe storms could devastate more forests than ever before. On the other hand, there is no empirical evidence of an increased frequency or magnitude of storms so far, neither in Central Europe (Schiesser, et al., 1997), in Scandinavia (Alexandersson, et al., 2000) and above the Northern Atlantic (Lefebvre, 2002) nor in the Urals (Lässig & Močalov, 2000). For Ukraine, almost no information on the frequency of severe natural disasters is available at present.

The Ukrainian Carpathians, situated in the west of Ukraine, occupy an area of ca. 24,000 km². This region is haunted by natural disasters like flooding, landslide and windthrow very often. At all times, windthrow has been the most important natural event damaging vast forest areas in this region.

In order to estimate the importance of frequent storms for forest dynamics and forest management in the Ukrainian Carpathians, the present study mainly deals with the question how often storms actually do occur in this region, and whether the number and intensity of severe storms are actually increasing.

The Carpathian Mountains constitute Europe's largest temperate forest ecosystems and are a biodiversity hotspot. The Ukrainian region of the Carpathians is particularly important, because it bridges the northern and southern Carpathians, and includes some of Europe's last and largest old-growth beech forests (Holubets, et al., 1988). Carpathian forests bear the legacy of a long history of intensive management dating to the Austria-Hungarian period and more recent forest management systems introduced under the Soviet regime. Much of the native beech (*Fagus sylvatica*) and mixed-species forests were converted to Norway spruce (*Picea abies*), native to the region but planted ubiquitously on non-endemic sites and using non-local genetic varieties (Krynytskyy & Tretiak, 2003). This, together with even-aged, plantation-style forest management practices, resulted in homogenized and simplified forest structure and composition at both stand and landscape scales (Stoyko, 1998). Mono-cultured plantations in the Carpathians have been susceptible to mortality agents, such as root rots and spruce

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bark beetle (*Ips typographus*), and have been stressed by airborne pollution. Collectively, these have contributed to spruce dieback.

Methods and Material

It is mainly wind gusts of more than 20 m/s that damage single trees or large forests (Rottmann, 1986). Therefore, we investigated extensive meteorological data on the occur-

rence and characteristics of strong winds from a region covering an area of more than 24,000 km². Data on storms with a (1 hour average) wind speed of 20 m/s or more was collected from 16 stations throughout this most westerly part of Ukraine (Fig. 1). For the study period, the date of each storm, its duration, the maximum speed of wind gusts measured and various data on temperature, precipitation and air pressure was recorded.



Figure 1. Meteorological stations in the Ukrainian Carpathians

To describe the frequency and intensity of strong winds in general which have been continuously recorded at more than one meteorological station, just one storm event with the highest wind speed recorded was used. In case of not continuously recorded wind currents (i.e.gaps), the data was analysed as if it was from two different storms. In case of storms which showed the same wind speed at more than one station, the one which lasted longest was analysed. In the following, storms measured at different stations are bundled in the analyses as one, so called, storm event.

To analyze the nature of forest windthrows in the Ukrainian Carpathians, we collected the forest inventory indexes for the stands where over 30 per cent of trees was damaged by strong wind. As a consequence, the forestry enterprises had to conduct a clear sanitation cutting in these areas. For each windthrow area we indicated the name of the forestry unit, the number of the compartment, and subcompartment, the date and the area, the stand composition, age, average height, average diameter, site class, stand density and the timber stock before the windfall as well as the volume of the trees fallen in the area. Such data was collected for the period of 1982-2002 from 36 forestry enterprises in the study region, of which 14 enterprises are in the Transcarpathian region, 12 – in Ivano-Frankivsk region, 6 – in Lviv region and 4 enterprises in Chernivtzi region. The abovementioned indexes were analysed for 2,976 windthrow areas.

Results

In the Ukrainian Carpathians strong winds were very frequent between 1945 and 1999. The weather stations in

the study area registered a total of 6,633 different strong winds with the speed of at least 20 m/s. The number of storms varied greatly from one year to another. The meteorological stations with the highest storm frequency are those located on the summits of Pozhezhevs'ka and Plaj mountains. These stations registered 59.0 and 50.3 times per year wind speeds of 20 m/s and more, on the average. The other stations which are less exposed to winds and located at lower altitudes showed smaller numbers of strong winds.

Overall, strong winds mainly came from south-west (Table. 1). They mainly hit forests on the leeward of the mountains facing north-east, especially in winter. The West of the mountain chain in the Transcarpathian region, where southwest-exposed slopes predominate, storm damage in forests was rare. At the meteorological stations Rus'ka-Mokra and Nyzhnij Studenny, for example, only two and seven storm events took place throughout the whole observation period.

The most frequent in the Ukrainian Carpathians are strong winds blowing from southwest. Thus, at the summit of Pozhezhevs'ka mountain they were recorded in this direction in 81% of cases, in Yaremche -73%, in Drohobych 55%, and, on the whole, the storm winds recorded at the meteorological stations in the Ukrainian Carpathians in 57% of the cases blew from south-west. Storms which came from the west predominated in Ivano-Frankivsk and Drohobych with 46 % and 27 %, respectively. But in the whole study region, only 14 percent of all storms came from this direction.

Table 1. Direction of strong winds ($v \geq 20$ m/s) recorded at 16 meteorological stations in the Ukrainian Carpathians (in % of total number)

Meteorological station	Total number of storms	Wind direction (%)							
		W	SW	S	SE	E	NE	N	NW
Plaj summit	1,609	4	53	17	6	3	9	5	3
Pozhezhevs'ka summit	2,421	14	81	1	1	1			2
Dolyna	497	23	54	6	2	1		1	13
Drohobych	251	27	55	6		1			11
Ivano-Frankivs'k	155	46	8	2	3	2			39
Kolomyja	122	29	15		2	2	2	2	48
Mizhgirja	119	2	4	58	7	4	1	10	14
Nyzhni Worota	49	12	18	23	4	2		29	12
Nyzhnij Studenny	7			72	14				14
Rakhiv	45	7	47	38		6	2		
Rus'ka Mokra	2		50				50		
Slavs'ke	52		17	67	4		2	8	2
Stryj	430	23	39	6	2	3	1	1	25
Turka	537	20	15	24	13	1	1	2	24
Velykyj Beresnyy	26	19	4	15	4	4	4	27	23
Yaremche	311	6	73	19			2		
Total	6,633	14	57	11	3	1	3	2	9

The strong wind direction in the valleys is substantially influenced by the direction of the valley. The meteorological stations Nyzhnij Studenny, Mizhgirja and Slavs'ke, for example, are situated in valleys which run from north to south. In these valleys the direction of storms which impinged on the Carpathians from the West and south-west had changed. Therefore, more than 50 per cent of all storms at these stations blew from the South. Storms coming from the North and the East were rare at most of the stations.

More than 60 per cent of the storms in the Carpathian mountains occurred between October and March (Fig. 2). In summer, with a minimum in August, only few storms were observed in this region. 55 per cent of the storms showed wind speeds between 20.0 and 24.9 m/s. In contrast, there was a total of 413 storms (6.2 %) showing wind speeds of 40 m/s or more. 88 per cent of them occurred in winter. These were mainly registered at the summits of Pozhezhevs'ka and Plaj mountains. At the meteorological stations in Yaremche, Stryj and Mizhgirja, for example, storms of such speeds were rarely recorded because they are situated in the valley bottom. No other station did show storms with such high wind speeds.

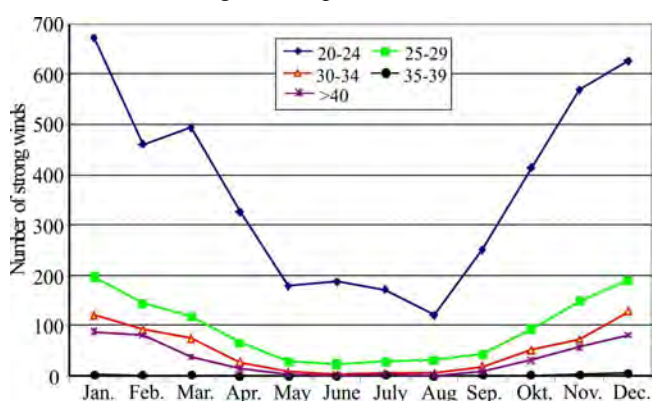


Figure 2. Number of strong winds at 16 meteorological stations in the Ukrainian Carpathians sorted by month and wind speed (m/s)

Winter storms usually lasted longer than summer storms. The average duration of a storm event was 5.0 hours in winter and 2.4 hours in summer. Overall, 80 per cent of the storms lasted between one and ten hours. Only few storms blew longer than 50 hours. In summer, thunder storms with severe gales sometimes occurred, lasting one hour or less. Long-lasting storms mainly occur at the mountain summits mentioned above. The majority of the long-

lasting storms occurred between November and March with a maximum in January (Fig. 3). The most long-lasting storm with a total duration of 96 hours was recorded in 1965 between February 25 and 28 at the summit of Pozhyzhevs'ka mountain. The second longest took 92 hours 50 minutes and happened in 1984 between February 11 and 14 at Plaj mountain.

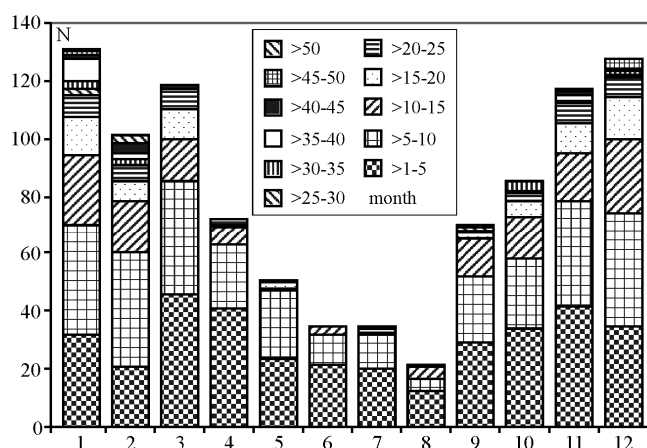


Figure 3. Number of storm events (N) at 16 meteorological stations in the Ukrainian Carpathians sorted by month and storm duration (h)

Severe storm events occurred every year almost everywhere in the Carpathians, but their frequency varied clearly from one year to another. But not only the number of storms in general, the number of extreme storms with wind speeds of more than 40 m/s also varies greatly. 1996 an annual maximum of 52 storm events was recorded.

In general, no significant trend in storm frequency could be detected for the region investigated. The meteorological stations which had registered the largest number of storms were the two highly elevated stations at the ridges of Pozhyzhev'ska and Plaj mountains. Despite the high variation from one year to another at these two mountain stations, the annual storm frequency increased with an annual rate of 0.5 storm. At the 14 lower elevated stations it has slightly decreased. But, for the period investigated no clear trend is visible. Storm frequency has, overall, cyclic character.

Severe storms combined with intensive rainfall very often cause windthrows in forests. On December 14th, 1964, for example, the daily amount of rainfall totalled 92.9 mm at Rus'ka Mokra, 90.5 mm at Mizhgirja and 59.6 mm at Nyzhnij Studenny. And on October 29th, 1992, 102.1 mm

of rain fell on the summit of Plaj mountain, in combination with gusts of 34 m/s. Both events caused large-scale windthrows. As a rule, the events like those mentioned above are comparatively rare. Usually, when storms occurred, daily precipitation depth was up to 19.9 mm.

Extent of windthrows

The most intensive windfalls were recorded in the Ukrainian Carpathians during 1957-1964. In this period, the totally and partially disturbed windthrow areas occupied 519,600 ha and windthrows damaged more than 21 million m³ of timber (Kalytzky, 1998). During these years the annual volume of timber damaged by natural disasters did not differ much from the amount of the annual cut, but in 1964 the volume of damaged timber was more than twice as much (Kiselevskyy-Babinin & Diakov, 1968). In December 1989 and in February 1990 the hurricanes damaged about 2.4 million m³ of timber in Ivano-Frankivsk region, including 133,800 m³ in the Carpathian National Park. Over 400,000 m³ of wood was damaged at the same time also in the *Synevyr* National Park in the Transcarpathian region (Stoyko, 1993).

The enterprises that suffered most of all from windthrows were as follows: the Vyhoda-, Vorohata- and Osmoloda state forestry enterprises of the Ivano-Frankivsk regional administration of forestry and the Ust'-Chorna-, Mizhgirja-, Yasinja- and Rakhiv state forestry enterprises of the Transcarpathian regional administration of forestry (Fig. 4).



Figure 4. Stand-replacing windstorms in the Vyhoda forestry enterprise

Thus, the main factors influencing windthrows depend on meteorological phenomena – i.e. strong winds and intensive precipitation. These factors are modified and often strengthened under the influence of orographic elements like mountain peaks and directions of valleys. The forest-biological features of associations of trees, that are responsible for biological stability of forest, resist the destroying power of windthrow-inducing factors (Kalytzky & Olijnyk, 2007). Among the complex of forest- and site factors, the most significant are the composition and structure of forest stands, their age and density.

The total area of the complete forest windthrows in the investigated enterprises amounted to 7,779 ha. The volume of the fallen timber made up 1.881 million m³, or, on the average, 238 m³ per ha. The amount of windthrows changes considerably from year to year. During the period of our studies we did not reveal any definite tendency either to-

wards decreasing or increasing the amount of forest windfalls in the Ukrainian Carpathians.

As was expected, the most frequent forest windthrows were observed in spruce stands. This species made up 72 per cent of the total volume of the fallen trees. The share of silver fir made up 13 per cent of the fallen timber while the share of beech amounted to 12 per cent. Other species made up only 3 per cent of the fallen trees. The share of spruce in the forest fund of the Ukrainian Carpathians makes up 43 per cent of the total forest land area, that is considerably less than its percentage in the fallen timber. The most wind-resistant species appeared to be beech stands – at a distribution of 39 per cent the share of beech in the total volume of the fallen timber made up only 12 per cent.

Taking into consideration the fact that the forest growth conditions on the North-Eastern macrohillside (Lviv-, Ivano-Frankivsk- and Chernivtzi regions) differ greatly from those of the South-Western macrohillside (Transcarpathian region), we analysed the windthrow area data individually for each macrohillside.

It turned out that on the South-Western macrohillside there was even greater difference between the share of spruce stands in the total forested area (29 per cent) and their part in the fallen trees – 76 per cent. The difference on the North-Eastern macrohillside was significantly less – with the share of spruce stands of 53 per cent in the total forested area – their part in the fallen trees made up 70 per cent. Therefore, the spruce forests in the Transcarpathian region are even more susceptible to windthrows than in the Precarpathian region.

The stands aged 71-80 and 81-90 years were damaged by windfalls most of all on the both macrohillsides. As a whole, the share of these two age classes amounted to 33.5 per cent of the total volume of the fallen trees on the South-Western macrohillside and 28.5 per cent on the North-Eastern macrohillside.

But in general, the windthrows affected forest stands of different age classes. The share of fallen trees among young growth- and middle-aged stands was considerably larger on the North-Eastern macrohillside. The reason is that after World War II there were created many pure artificial stands of spruce and pine in this region, forest growth conditions being unfavourable for these species. The South-Western macrohillside, on the contrary, showed a larger share of fallen trees in mature stands. This is because the middle age of forest stands in the Transcarpathian region is much higher.

It has been found that the windthrows in the Ukrainian Carpathians damaged the stands with the average height of 26 to 30 m most of all both on the North-Eastern- and on the South-Western macrohillsides (Fig. 5). A distinguishing characteristic of the South-Western macrohillside was that for high site class stands with a height ranging from 31 to 35 m (32.5 per cent of the total forested area) and ≥ 35 m (8 per cent) the damage share was significant. This is due to a higher level middle age of the stands and somewhat better forest growth conditions in the Transcarpathian region.

It is these factors that were responsible as well for a larger average diameter of the fallen trees on the South-Western macrohillside. The largest share there (36 per cent) was the average diameter of 41 to 45 cm, whereas on the North-Eastern macrohillside the average diameter was 26 to 30 cm (27 per cent) and 31 to 35 cm (23 per cent).

As to the density of stands, the trend was the same both on the North-Eastern- and on the South-Western macro-

hillside – on both of them the windthrows damaged most of all the middle-density stands.

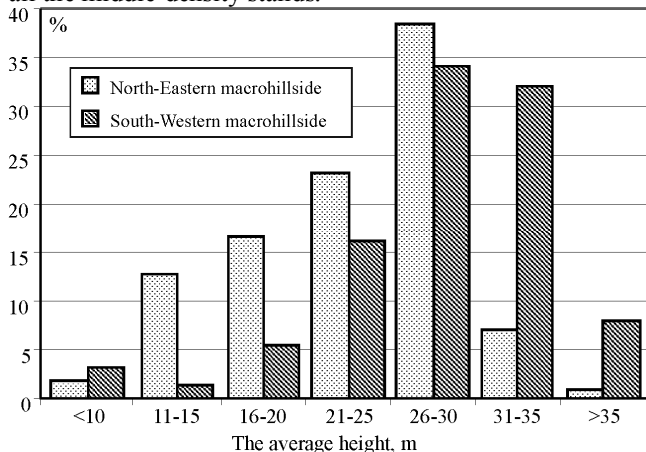


Figure 5. Distribution of the windthrows according to the average height of affected stands

The methods for mitigating the storm damage to forests

In order to decrease wind-induced damage to forests in the Ukrainian Carpathians, foresters should create the windfirm stands. To achieve this goal, it is necessary to enhance windfirmness of stands. It is important to ensure optimal interrelation between the diameter and height of tree trunk in the wind-dangerous places, it is advisable to create less dense mixed forest cultures with their number of 4 to 5 thousand units per ha (Stoyko, 1993). Also, it is more advisable to plant mixed beech-silver fir-spruce stands where the share of spruce should not be higher than 50 to 60 %. The main species on the stony soils should be a Scots pine and European cedar pine. There should be also formed windbreaks at the border of forests. The trees at this zone must have deep, well-developed root systems and long crowns.

One of the important goals of the semi-natural forest management is forming stand composition adjusted to the biotope and forest structure which is resistant to unfavorable natural disturbances, first of all to strong winds.

Conclusions

Concerning global climate changes, it is obvious that the increase of temperature is definitely taking place in the Ukrainian Carpathians. But this has not resulted in a higher frequency of storm events, so far. Therefore neither foresters nor forest scientists have to fear, yet, that severe storms will have more negative effects on forest management than ever before. This is on condition that the average stand height (often re-calculated from the stand volume) of the forests persists at the same level. If the stand volume rises, there is an increased probability of windthrows. There is no doubt that, in this mountain region, wind is an important site factor which regularly forms the local as well as the regional structure of forests.

The number of storms at each station varied greatly from one year to another and showed cyclical character. The storms occurred mainly in the wintertime. Winter storms usually lasted longer than summer storms. Overall, 57 per cent of the storms at the meteorological stations in the Ukrainian Carpathians, 57 percent blew from south-west.

The results of our investigation has confirmed that wind damage to forests in the Ukrainian Carpathians varies greatly in scale and effect from year to year. Windthrows in

this region are common natural phenomena. They may occur in the stands of various composition, age, height, diameter and density. In the last few decades the windthrows in the Ukrainian Carpathians have been only of local character and they have not done sizable damage to the forests. Most often they took place in spruce forests aged from 71 to 90 years, with the average height of stands of 26-30 m. Foresters cannot prevent them from arising, but they can reduce the extent of windthrows through the proper forestry management. They have to form mixed, uneven-aged and multi-storeyed stands.

Ecologically, windthrows maybe said to be of positive significance. The restoration of native species composition in areas dominated by spruce plantations will both enhance forest health and play an important role in biodiversity conservation.

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ВІТРОВАЛИ ЛІСУ В УКРАЇНСЬКИХ КАРПАТАХ

Проаналізовано літературні джерела щодо взаємозв'язку між частотою та інтенсивністю сильних вітрів і змінами клімату. За даними 16 метеостанцій проаналізовано повторюваність та інтенсивність сильних вітрів (зі швидкістю вітру ≥ 20 м/с) у регіоні Українських Карпатах. Річна кількість фіксованих сильних вітрів в Українських Карпатах значно варіює з року в рік без достовірного тренду до збільшення чи зменшення. Частіше штормові явища реєструвались у зимовий період, тоді ж вони мали і більшу тривалість. Серед румбів сильних вітрів домінував південно-західний напрям. Проаналізовано вплив складу, віку, середньої висоти, середнього діаметра та повноти деревостанів на прояв вітровалів лісу в Українських Карпатах. Загалом вітровали лісу мали локальний характер і найбільше пошкодили в регіоні досліджень середньоповнотні деревостани віком 71-90 років з середньою висотою 26-30 м. Найбільшої шкоди від вітровалів лісу лісгосподарські підприємства зазнали в 1990, 2000 і 2002 рр. Найчастіше пошкоджувалися чисті ялинові ліси. Наведено шляхи підвищення вітростійкості ялинових деревостанів Українських Карпат.

Ключові слова: природні стихійні явища; вітровали лісу; лісознавство, лісівництво.

ВЕТРОВАЛЫ ЛЕСА В УКРАИНСКИХ КАРПАТАХ

Сделан анализ литературных источников относительно взаимосвязи между частотой и интенсивностью сильных ветров и изменениями климата. По данным 16 метеостанций проанализированы повторяемость и интенсивность сильных ветров (со скоростью ветра ≥ 20 м/с) в регионе Украинских Карпат. Годовое количество зафиксированных сильных ветров в Украинских Карпатах значительно варьирует из года в год без существенного тренда к увеличению или уменьшению. Чаще штормовые явления регистрировались в зимний период, тогда же они имели и большую продолжительность. Среди румбов сильных ветров доминировало юго-западное направление. Проанализировано влияние состава, возраста, средней высоты, среднего диаметра и полноты древостоев на проявление ветровалов леса в Украинских Карпатах. В общем ветровалы леса имели локальный характер и больше всего повредили в регионе исследований среднеполнотные древостои возрастом 71-90 лет со средней высотой 26-30 м. Наибольший вред от ветровалов леса лесохозяйственные предприятия получили в 1990, 2000 и 2002 гг. Чаще всего повреждались чистые еловые леса. Указаны пути повышения ветроустойчивости еловых древостоев Украинских Карпат.

Ключевые слова: природные стихийные явления; ветровалы леса; лесоведение; лесоводство.