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WINDTHROW FACTORS – A CASE STUDY ON POKLJUKA

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Abstract:
This paper presents a case study in windthrow. The case study area was 1.7 ha of two forest gaps on the Pokljuka plateau, Slovenia, where strong wind had blown down 44 trees. An additional 44 standing trees closest to the fallen trees were used as a control group for comparative purposes. The following variables were measured for fallen trees: breast diameter, height, crown diameter and height as well, the number and diameter of roots, the volume of the root system, and root rot. Standing trees were measured for breast diameter, height, crown diameter and height, and the number and diameter of roots. The data were analysed using the machine learning methods in the Weka computer program. The most important factors of windthrow in the case study area were: storm wind (speed above 17 m/s), wet shallow soil, and the edges of the forest gaps. The results of the case study show that breast diameter, tree height and the presence of root rot can be classified as windthrow factors.

Key words: wind, windthrow, *Picea abies*, Pokljuka, root rot, *Heterobasidion sp*., factors of windthrow

DEJAVNIKI VETROLOMA NA PRIMERU VETROLOMA NA POKLJUKI

Izvleček:
V raziskavi smo izdelali študijo primera vetroloma, ki je zajemala dve vrzeli, veliki 1,7 ha. V vrzelih je viharen veter podrl 44 dreves. Za primerjavo smo vzeli še 44 najbližjih stoječih dreves. Podrtim drevesom smo izmerili prsni premer, višino, širino in višino krošnje, število in debelino korenin, izračunali volumen koreninskega sistema ter vzeli izvrtek, s katerim smo ugotavljali trohnobo. Najbližje stoječim drevesom smo izmerili prsni premer, višino, širino in višino krošnje, število in debelino korenin. Analizo podatkov smo poleg statističnih obdelav izvedli tudi z metodami strojnega učenja v računalniškem programu Weka. Najpomembnejši dejavniki za podrtje dreves na mestu študije primera so bili: viharen veter (hitrost nad 17 m/s), razmočena in plitva tla ter gozdni rob vrzeli. Rezultati raziskave so pokazali, da so pomembno vplivali k podrtju dreves tudi prsni premer, višina dreves in trohnoba.

Ključne besede: veter, vetrolom, *Picea abies*, Pokljuka, rdeča trohnoba, *Heterobasidion sp*., dejavniki vetroloma

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VSEBINA

1 INTRODUCTION
UVOD

Strong wind is defined as being of force 6 to 7 on the Beaufort scale (10.8-17.1 m/s). Such wind moves thick branches on trees or even shakes entire trees, whistling of high tension wires can be heard, and using an umbrella or even walking against the wind is difficult. In storm winds of force 8 or higher on the Beaufort scale (>17.1 m/s), tree branches are broken, walking against the wind is no longer possible, and damage to buildings (chimneys destroyed, gutters pulled off, and roofs torn off) is often incurred (PETKOVŠEK / LEDER 1990).

In Slovenia there was approximately 565,500 m^3 of sanitary felling in the year 2002, which represents 21 % of the total felling in Slovenia (JURC et al. 2003). As a result of windthrows, 64,243 m^3 of trees fell, a large percentage of them on the Pokljuka plateau.

From November 14 to November 16, 2002, a storm wind blew over Slovenia causing a great deal of damage to the Upper Sava Valley and to the regions of Podravje, Primorska, Gorenjska and central Slovenia. In lower lying parts of Slovenia the wind reached 20 m/s (72 km/h), while in Alpine valleys and higher lying areas the intensity of the wind reached hurricane levels. The meteorological stations in Bovec and on Kredarica measured wind gusts of around 50 m/s or 180 km/h (GREGORIČ / GREGORČIČ / BERTALANIČ 2002).

The wind inflicted the most damage to the forests of Pokljuka, where, according to the first reports, extremely strong gusts of wind out of the southwest destroyed approximately 21,000 m^3 of trees (ZAPLOTNIK 2002). Evaluations for state forests show that 18,000 m^3 trees fell on the Pokljuka plateau, 1000 m^3 on Mežakla and 500 m^3 in the Radovna valley, while in privately owned forests an additional 1500 m^3 of trees fell. The wind hit exposed elevations at Kokošnjica, Jerebikovec and Lipenščov vrh, and the southwestern face, consisting of old stands with larger areas of young forest and Alpine pastures, was also hard hit.

The Forest Protection Report of the Slovene Forestry Service, Bled Regional Unit for 2002 writes in the chapter on windthrow that the storm out of the southwest on Pokljuka felled trees individually and over small areas. The hardest hit trees were those with weak root systems, trees infected with root rot, as well as trees in Alpine meadows, on roads, young trees and trees at highest elevations. The majority of affected trees were tipped over, while 10% of them were broken. The greatest amount of breakage occurred at the following locations: Belska planina, Za Ribnico, Rudna dolina, Mesnovec, Za mostičem, and Jerebikovec (Poročilo o varstvu…2002).

Trees are like levers in that they are fixed to the ground, but the above ground portions can swing about freely (STATHERS / ROLLERSON / MITCHELL 1994). On the other hand, the crown of the tree acts as a sail, and the wind can apply considerable tractive force to the crown. The tractive force on the crown multiplied by the lever action of the breast is a factor which contributes to the overturning of a tree. Since trees are flexible, their crowns can move under the force of the wind, which is an additional factor determining whether they will overturn or not. As trees grow, the length of the lever increases. This means that the overturn factor increases, although the size of the crown stays the same. The resistance of the trunk and the roots/soil allows the trees to resist breaking or being uprooted (ibid.). Strong pointed trunks can resist bending and remain upright, which decreases the momentum. The resistance of the root system to overturning is dependent on the strength of the roots, the level of development of the root system, the amount of soil around the roots, and the cohesiveness of the connection between the roots and the soil. When the trunk sways back and forth during stormy weather, the natural resistance of the trunk is not decreased, but rather the cohesiveness of the connection between the roots and the soil can be lost, particularly in the case of very moist soils.

Mountain spruce forest is composed of tree clusters and single standing trees. SOČAN (1989) made a research of a tree cluster and its mechanical strength. He found out that tree clusters make forest stands more resistant to strong winds. Cluster rigidity depends on the density, form and age of the member trees. The trees on the windward side of the cluster transfer the windload to the neighbouring trees in the cluster during crown contact. A large number of trees in the cluster improves resistance to wind (SOČAN 1989, MLINŠEK 1975).

There are five groups of environmental factors which influence the danger of windthrows: individual tree characteristics, stand characteristics, root zone soil characteristics, topographic exposure characteristics, and meteorological conditions (STATHERS / ROLLERSON / MITCHELL 1994). During the windthrow on Pokljuka the wind mostly felled individual trees and those in smaller groups. The key question is why the wind felled a particular tree and not the neighboring ones. There may be several factors influencing this. In this study, we will limit ourselves to the factors connected to an individual tree and its dimensions. The study considered the following variables: breast diameter, tree height, crown length and width, and the distance to the nearest standing neighboring tree. We were interested to find out whether there was any rule behind the above variables dictating whether a given tree would overturn due to strong winds.

2 METHODS
METODE DELA

Windthrow is the sole focus of this study. The case study area was situated at the foothills of Mesnovec (Figure 1). In this case, the windthrow took place in two forest gaps measuring 1.7 ha (Figure 2). The average slope of the surface was 20.8 % (+/- 8.5 % with 95 % accuracy). The exposure of the study area was mostly southwestern. The soil depth was 23 cm +/- 8 cm (with 95 % accuracy).

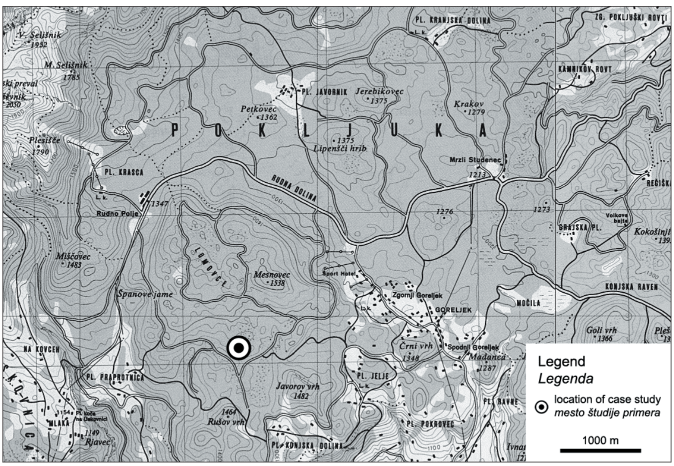

Figure 1: Map of the relevant part of Pokljuka with the location of the case study marked (Source: Interaktivni atlas Slovenije 1998)
Slika 1: Karta dela Pokljuke in oznaka mesta študija primera (Vir: Interaktivni atlas Slovenije 1998)

A total of 44 trees were felled in the study area. In order to determine why one tree fell and another did not, we measured 44 standing trees closest to the fallen trees. All of the fallen trees and all of their nearest neighbors were Norway spruce (*Picea abies* L.) Karsten). The wind felled trees in two groups and a few individual trees in the study area (Figure 2). 35 trees were thrown by the wind, 6 were stock broken and 3 were trunk broken. Breaks were classified according to ŽGAJNAR (1990) and STATHERS / ROLLERSON / MITCHELL (1994). Trees lay on the ground at azimuth 333° to 92° (clockwise).

For the purpose of our study, we assumed that the wind felled the trees at once, which allowed us to keep the wind speed and wind direction constant. We focused on the dimensions of the trees as those tree characteristics that were easily surveyed.

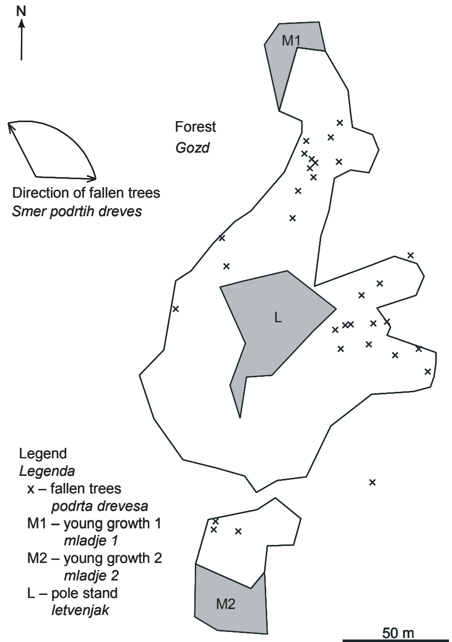

Figure 2: Ground plan of the case study location (x marks the 31 fallen trees - 13 of which are forked trees, a total of 44 trees)
Slika 2: Tloris lokacije študije primera (na sliki je z znakom "x" prikazano 31 podrtih dreves, med njimi je 13 dvojnih debel, t.j. skupaj 44 debel)

Since the wind had uprooted the majority of trees, we had the opportunity to survey the soil depth and the volume of the root system. In order to calculate the volume of the root system we assumed that the root system was made of cylinders and cones. We calculated the largest and the smallest diameter of the root system, the depth of the root system at its edges and the depth of the root system at the trunk.

Monitoring forms were prepared to collect data in the field. The data collected in the field were input into a relational database using Microsoft Access. The following variables were included in our analysis:

- PN is the dependent variable; this discrete variable takes the values 0 and 1 (1 means a fallen tree, 0 means a standing tree);
- R is the variable that refers to the breast diameter in centimeters;
- RK is the variable that refers to the width of the crown of the tree in meters;
- RC is the variable that refers to the distance to the nearest standing neighboring tree in meters;
- HK is the variable that refers to the height of the crown in meters;

- H is the variable that refers to the height of the tree in meters;
- K is the variable that refers to the number of main roots in the root system;
- T is a discrete variable which takes a value of 0 or 1 (1 means a fallen tree with root rot, 0 means a fallen tree without root rot).

The presence of spruce root rot on trees fallen due to windthrow was determined by the following methods (MUNDA 1996, JURC 2001):

1. On trees suspected to be infected with root rot (Hetererobasidion sp.), we bored a hole using a Pressler drill or a manual borer. A tree is very likely to be infected with root rot if the sawed or broken surface is colored at any point (even small differences in the shade of color from the rest of the wood can be indicative). The borehole is made on the side of the trunk suspected of being infected with root rot. If the borehole is made in a tree stump, it is made at least 10 cm from the edge of the stump since the surface area of the stump can be dried out and other fungi may be present. The borehole is drilled deep enough for us to reach the edge of the colored area and drill a few centimeters into the colored wood.
2. A bag containing a moist filter paper is prepared, and the bored sample is placed onto the moist filter paper. A little air is let into the bag and it is closed air-tight with an elastic band. Data (date, location, sample number, tree number) about the sample are written in pencil on a slip of paper and placed in the bag as well. The bag containing the bored sample is kept at room temperature for 7-14 days, during which time the sample is not touched.
3. Before boring the next bore sample, the Pressler drill is disinfected with ethanol (96 %). The procedure is repeated for the remaining samples as set out in points 1 and 2.
4. After 7-14 days, the samples are checked under a magnifying glass. If the bore sample shows a damp white colored film, which is the conidiophore with conidia of root rot, then this is a positive sign that the trunk is infected with root rot (JURC 2001).

Through our analysis we hoped to determine a connection between the independent variables R, RK, RC and HK, and the dependent variable PN. The Weka computer program (WITTEN / FRANK 1999) using the J48 decision tree induction method (QUINLAN 1986) was selected as the appropriate machine learning method for the decision trees. A decision tree is a hierarchical structure where each internal node uses a test on an attribute, each branch corresponds to an outcome of the test, and each leaf gives a prediction for the value of the dependent class variable (DŽEROSKI 2001).

Basic statistical information (average, variance, standard deviation) was carried out by using the computer program Statgraphics Plus for Windows 4.0. The following variables were used in the statistical calculations: the number and thickness of the roots, the breast diameter, the height of the tree, and the height and width of the crown. These variables were measured for each fallen tree and the tree standing nearest to it. The number and thickness of the roots were counted and measured at the point where the roots enter the soil. The breast diameter was measured using a Mantax Digitech digital calliper from the Swedish producer Haglöf, according to the method used for taking forest inventories (HOČEVAR 1995). In measuring breast diameter we encountered some special cases, e.g. 13 forked trees. The height and width of the crowns of fallen trees were measured using an ultrasound remote measuring unit. The height of the standing trees was measured using a Suunto hypsometer after trigonometric principle (ibid.).

In this study we wanted to test the null hypothesis to determine whether there is a statistically significant difference between the arithmetic means of the studied variables between fallen and standing trees. A simple analysis of variance was used to test the presented null hypothesis. In order to justify using variance analysis, we tested the homogeneity of the variance according to Bartlett and Cochran, which showed that there was no statistical difference in variance between the studied variables.

3 RESULTS
REZULTATI

The accuracy of the forecasts is evident in the probability of correct classification (BRATKO / DŽEROSKI / KOMPARE 2003). The J48 method for the given parameters classified 77.0 % of the samples into the proper class. Fallen trees (PN = 1) were correctly classified in 78.6 % of cases, while standing trees (PN = 0) were correctly classified in 75.6 %. The learning algorithm was given 87 entries. To evaluate the accuracy we used 87 cross-validations.

The decision tree learner J48 divides the 87 records into 6 leaves (Figure 3). The most important classification factor is breast diameter, followed by the width of the crown and the distance to the nearest standing neighbor. The trees with a diameter of 48 cm or less were generally knocked over, while trees with a diameter over 48 cm were generally left standing. The greatest number of fallen trees had a narrow trunk and a wide crown. The most stable trees were those with a large breast diameter and a narrow crown. The distance to the nearest neighbor was most important for the trees with the narrowest (<= 4.6 m) and widest crowns (> 5.5 m). The RC factor in trees with a small breast diameter and with wider crowns appears to be quite decisive in determining whether a tree will fall or not; if the distance to the nearest standing neighbor is more than 3.5 m, there is a greater chance that the tree will remain standing. In thicker trees with wider crowns the decisive value for RC is 6.5 m; approximately the same number of trees fell that were below this value as above it.

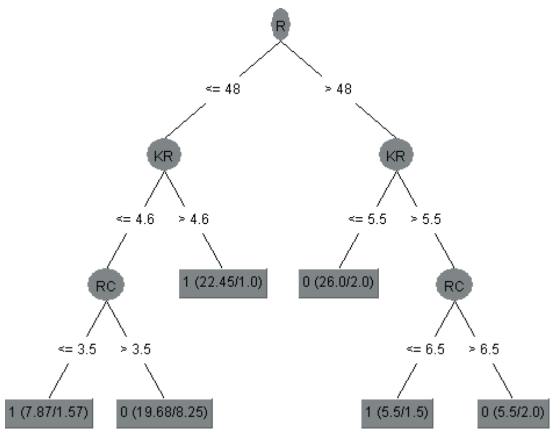

Figure 3: Classification tree learnt by J48 method
Slika 3: Klasifikacijsko drevo naučeno s programom J48

From the holes bored in the trunk and the color of those bored areas, we determined that 24 out of 44 trees were infected with root rot (55 %). The subsequent culturing and miscroscopic analyses showed that 17 trees were infected with the fungus *Heterobasidion* sp. (Figure 4). The remaining 7 bored samples showed infection with fungi of the genus *Ceratocystis*, which clarifies why some of the bored samples were colored (Figure 5). After harvesting the fallen trees we took photographs of all the remaining stumps and used the UTHSCSA ImageTool 3.00 computer program to determine the surface area covered by root rot (Figure 6). We determined that by boring we only caught those root-rot infected trunks where the root rot covered more than 15 % of the surface of the cut trunk.

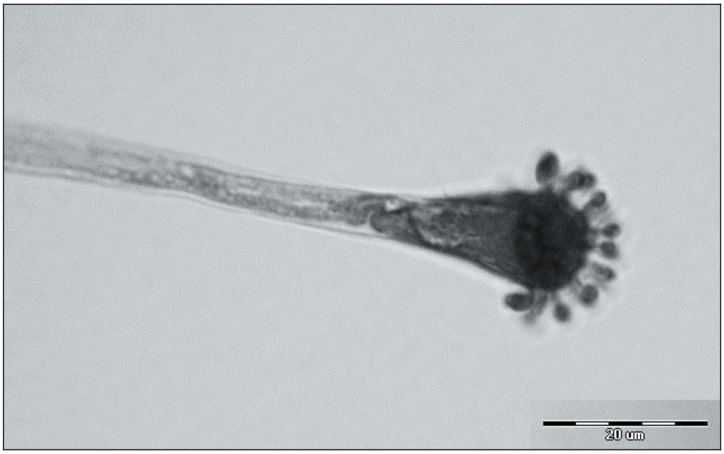

Figure 4: Microscopic photo of a conidiophore with conidia of *Heterobasidion* sp. (Photo by Nikica Ogris)
Slika 4: Mikroskopska slika konidiofora s konidiji *Heterobasidion* sp. (Foto: Nikica Ogris)

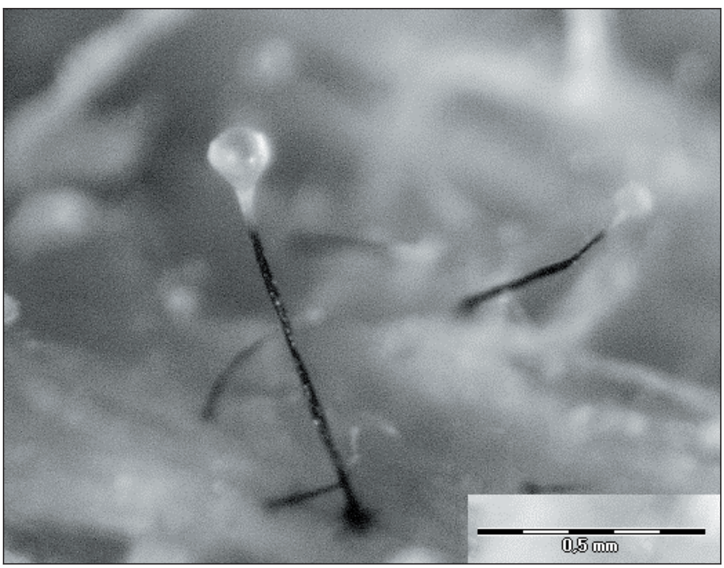

Figure 5: Fungus of the genus *Ceratocystis* on wood (Photo by Nikica Ogris)
Slika 5: Gliva rodu *Ceratocystis* na lesu (Foto: Nikica Ogris)

Figure 6: Hollow stump (Photo by Nikica Ogris)
Slika 6: Votel panj (Foto: Nikica Ogris)

The volume or the weight of the root system is one of the decisive factors that influence whether a tree will fall as a result of high winds. Since the trees were mostly uprooted, we were able to measure the volume of the spruces' "plates". The 95 % confidence interval for the mean volume of the root system is 2.8 m^3 +/- 1.0 m^3. The variability in the data is huge and therefore does not help to clarify why these spruces fell.

An analysis of the number and thickness of the roots in the root system showed that there is no distinctive difference between fallen and standing trees (Table 1). We can conclude that in our case, the number and thickness of the roots measured at the rootstock is not a factor which aids in overturning trees due to high winds.

Table 1: Summary statistics for the number and thickness of roots
Preglednica 1: Osnovni statistični znaki za število in debelino korenin

Summary statistics Statistični kazalec	Number of roots (n=75) Število korenin		Thickness of roots (n=443) Debelina korenin	
	fallen trees podrta drevesa (n=32)	standing trees stoječa drevesa (n=43)	fallen trees podrta drevesa (n=202)	standing trees stoječa drevesa (n=241)
Average Povprečje	5.53	5.60	18.96 cm	19.01 cm
95% confidence interval 95 % interval zaupanja	+/- 0.68	+/- 0.46	+/- 1.05 cm	+/- 0.84 cm
Variance Varianca	3.55	2.38	57.20	44.01
Standard deviation Standardni odklon	1.88	1.54	7.56	6.63
Analysis of variance Analiza variance	p = 0.6176		p = 0.2022	

The analysis of variance for the breast diameter and the height of the tree (Table 2), as well as for the width and height of the crown (Table 3), showed that at 95 % confidence level there is a statistically significant difference between fallen and standing trees only in the mean of the breast diameter. The analysis of variance for the tree height also showed quite a small p (0.08). Therefore, we believe that the height of trees is one of the possible factors in the overturning of trees. The difference in crown width and height between the fallen and standing trees was not large enough to be statistically significant. The breast diameter of the fallen trees was around 7 cm smaller than in the standing trees. The height of the fallen trees was around 1.6 m lower than the height of the standing trees. The mean crown width of the fallen trees was around 0.5 m greater than in the nearest standing trees. The height of the crown of the fallen trees was a good 4 m smaller than that of standing trees.

Table 2: Basic statistics for breast diameter and height of trees (n=87)
Preglednica 2: Osnovni statistični znaki za prsni premer in višino dreves (n=87)

Summary statistics Statistični kazalec	Breast diameter Prsni premer		Height of trees Višina dreves	
	fallen trees podrta drevesa	standing trees stoječa drevesa	fallen trees podrta drevesa	standing trees stoječa drevesa
Average Povprečje	43.23 cm	50.44 cm	30.06 m	32.64 m
95% confidence interval 95 % interval zaupanja	+/- 3.39 cm	+/- 2.92 cm	+/- 1.49 m	+/- 1.17 m
Variance Varianca	124.09	90.11	23.97	14.52
Standard deviation Standardni odklon	11.14	9.49	4.90	3.81
Analysis of variance Analiza variance	p = 0.0023		p = 0.0817	

Table 3: Basic statistics for diameter and height of crowns (n=87)
Preglednica 3: Osnovni statistični znaki za širino in višino krošenj (n=87)

Summary statistics Statistični kazalec	Diameter of crowns Širina krošenj		Height of crowns Višina krošenj	
	fallen trees podrta drevesa	standing trees stoječa drevesa	fallen trees podrta drevesa	standing trees stoječa drevesa
Average Povprečje	4.97 m	4.50 m	16.95 m	21.34 m
95% confidence interval 95 % interval zaupanja	+/- 0.37	+/- 0.37	+/- 1.96	+/- 1.90
Variance Varianca	1.47	1.23	40.58	38.07
Standard deviation Standardni odklon	1.21	1.11	6.37	6.17
Analysis of variance Analiza variance	p = 0.2374		p = 0.2365	

4 DISCUSSION AND CONCLUSIONS
RAZPRAVA IN ZAKLJUČKI

We assume that the following factors were most important for this case study: storm wind, wet shallow soil, and the edges of the forest gaps. Not even strongly rooted trees with thick breast diameters and narrow crowns can protect themselves from the effects of storm winds. Wet soil does not provide enough support for the trees to resist strong winds. There had already been forest gaps in the forest prior to the windthrow, and the 2002 windthrow only widened them. Despite windthrow being the main cause of fallen trees, our analysis of collected data showed that there are also other factors involved.

The decision tree learning method J48 has a relatively large classification error. The main reason for this is the lack of data at a given number of variables. In order to improve the accuracy, we would have to collect more data. Despite the large number of errors, we can infer from the decision tree that in our study the most important factor in windthrow is the diameter of the tree (Figure 3). The results showed that wider trees (with a breast diameter of over 48 cm) were more wind resistant. This is understandable given that the bending moment of the tree rises by the cube of the breast diameter (SOČAN 1989, PELTOLA *et al*. 2000). The second important classification factor is the width of the crown. Spruces with narrow and long crowns are more stable, since their crowns have a smaller surface area and fewer places where the wind can take hold (MLINŠEK 1966, ZUPANČIČ 1969, BLEIWEIS 1983, SOČAN 1989). The study did not take into account crown asymmetries which can cause torsion in the crown when the wind blows and can therefore also be an important factor in windthrow (SKATTER / KUCERA 2000).

Tree rot is another reason why trees fall. WHITNEY *et al*. (2002) also determined that there is more rot in trees in windthrow areas. In our case study, more than half (55 %) of the fallen trees had root rot. The majority of the rotted trees were infected with the fungi of the genus *Heterobasidion*. Out of 44 fallen trees 17 were mechanically damaged (39 %). Of the 17 mechanically damaged trees, 9 were rotted. Research has shown that trees are most often infected with the fungi of the genus *Heterobasidion* through their roots (STENLID / REDFERN 1998). Mechanical damage can, however, be one of the possible entry points for the fungus. Therefore, in our case, it is likely that the rotted tree was infected through mechanical damage to the bark, but this cannot be proven.

Norway spruce is generally taken to have a shallow root system up to 30 cm deep (MLAKAR 1990). However, newer research does not agree with this general assertion (PUHE

2003). Norway spruce has the ability and can, under certain conditions, develop quite deep roots. In this case study, spruce trees had a shallow root system (23 cm +/- 8 cm) due to the shallow soil (approx. 30 cm) and it was this shallow root system which was one of the more important factors in felling trees. An important factor in the static stability of the tree is the number of thick roots, particularly those more than 10 cm wide (KODRÍK / KODRÍK 2002). However, the number and thickness of the roots and the volume of the root system were not decisive factors in our case study. Due to the shallowness of the root system the majority of trees were uprooted, just as in the large windthrow of November 16, 1963 (BERNIK 1966). In that case, the soil, as in our case, was very wet and the winds reached 8 and 9 on the Beaufort scale, felling 51,000 m^3 of trees in a few hours. Windthrow has been a problem on Pokljuka for a long time. Old forest managers know the problem well and have always considered windthrow in their work noting that shallow soil is a poor foundation for the forest's resistance to wind (WRABER 1950, ZUPANČIČ 1969).

Fallen trees were somewhat thinner and smaller, while the nearest standing trees were thicker and higher. Thicker trees have a higher flexural stiffness (BRÜCHERT / BECKER / SPECK 2000). Our research confirms that the thickness of the tree is important for its mechanical stability. The results of the analysis into the width and height of the crown of fallen trees and the nearest standing neighbors go somewhat against the previous research. The fallen trees had a larger crown width but a smaller crown height. The surface areas of the crown of the fallen trees were as small as the surface area of the crowns of standing trees. Therefore, it seems doubtful that the surface area of the crown was the decisive factor in windthrows in our case.

It would have been interesting to include other characteristics of the tree, such as: the density of the crown, the elasticity of the trunk, the density of the wood, the weight of the roots, and the resistance of the roots and soil. Inclusion of the above-mentioned variables in the data analysis using statistical methods and machine learning methods would have given added legitimacy to the reasons for fallen trees due to strong gales and storm winds.

Ulanova (2000) reviewed the effects of windthrow on boreal forests at different spatial scales: landscape, forest community, and fallen tree ecosystem. One of the results of windthrow are forest gaps. The scales of windthrow gaps in space and time determine the patch structure of the forest ecosystems. The main result of this phenomenon is the occurrence of gap-phase dynamics in forest communities. The development of gaps is very important for the survival of small- and broad-leaved trees in boreal coniferous forests (ibid), as could be said for the forests of Pokljuka. Windhtrow disturbances create pit-and-mound topography. The spatial distribution of trees is associated with pit-and-mound topography. Spruce regenerates better on mounds and fallen trees than on undisturbed surfaces (ibid).

Windfall disturbances play an important role in increasing biodiversity in forest ecosystem.

Windthrow is one of many stress factors that are part of the life of a forest. Windthrow is classified as an acute, simple, and natural disturbance (ANKO 1993). Windthrow as well as all other disturbances deserve special attention in the managing measures for the multiple-use forest because they reduce plasticity and responsiveness of the forest ecosystem to forest management measures and of its carrying capacity for various functions (ibid). Therefore, we should deal with disturbances from ecosystematic perspective and analyze their structure and functioning (ibid). Knowing all this, it changes borders of classical comprehensible forest protection.

5 POVZETEK

16. in 17. novembra 2002 je na Pokljuki pihal močen veter 8. stopnje po Beaufortovi skali. Prve ocene so nakazovale, da je padlo 21.000 m^3 drevja. Dejavnike vetroloma lahko razdelimo v naslednje skupine: lastnosti posameznega drevesa, lastnosti sestoja, lastnosti korenin in tal, lastnosti topografske izpostavljenosti in meteorološke pogoje. V študiji primera vetroloma na Pokljuki so bila drevesa večinoma podrta posamič ali v majhnih skupinicah. Zanimalo nas je, zakaj so bila drevesa podrta večinoma posamič. Obravnavali smo naslednje spremenljivke: prsni premer, višina drevesa, premer in višina krošnje, razdalja do najbližjega stoječega soseda, število in premer korenin, volumen koreninskega sistema in trohnoba. V raziskavi smo poskušali med proučevanimi spremenljivkami odkriti pravilo, ki je morda narekovalo, da se je drevo podrlo zaradi močnega vetra.

V raziskavi smo naredili študijo primera. Ploskev študije primera je bila 1,7 ha velika vrzel (Slika 2). Na ploskvi je podrlo skupaj 44 dreves. Izmerili smo še 44 stoječih dreves, ki so bila najbližja podrtim. Vsa drevesa so bila navadne smreke (*Picea abies* L.) Karsten). 35 dreves je veter izruval, 6 odlomil in 3 prelomil.

Analiza podatkov je bila narejena z metodo za učenje odločitvenih dreves J48 v računalniškem programu Weka. Statistične analize so bile izvedene v računalniškem programu Statgraphics Plus for Windows. Podatki so bili zbrani v relacijski podatkovni zbirki Microsoft Access.

Naučeno odločitveno drevo J48 je razdelilo 87 podatkov v 6 listov (Slika 3). Metoda J48 je pravilno razvrstila 77 % primerov vzorcev v ustrezen razred. Najpomembnejši dejavnik za razvrščanje je bil prsni premer drevesa. Drevesa s prsnim premerom 48 cm ali manj so bila v večini podrta. Širina krošnje in razdalja do najbližjega stoječega drevesa sta bila tudi izbrana kot pomembna dejavnika za razvrščanje. Najbolj stabilna drevesa so imela velik prsni premer in ozko krošnjo. Večina podrtih dreves je bila bližje novemu nastalemu gozdnemu robu.

Med 44 podrtimi drevesi je bilo 24 trohnečih. 17 jih je bilo okuženo z glivo iz rodu *Heterobasidion* in 7 z glivo iz rodu *Ceratocystis*. Ker je bila večina dreves izkoreninjenih, smo lahko izmerili volumen koreninskega sistema. Volumen koreninskih sistemov smrek je bil 2,8 m^3 +/- 1,0 m^3. Analiza srednjega števila in debeline korenin je pokazala, da ni statistično značilnih razlik med podrtimi in stoječimi drevesi (Preglednica 1).

Naredili smo tudi enostavno analizo variance (Preglednica 2 in 3). Preizkušali smo enakost aritmetičnih sredin med podrtimi in stoječimi drevesi v naslednjih posameznih spremenljivkah: prsni premer, višina drevesa, širina in višina krošnje. Pri 95 % intervalu zaupanja se je med obravnavanimi spremenljivkami pokazal za statistično značilno različnega le prsni premer.

Zaključili smo, da so bili na ploskvi študije primera za nastanek vetroloma verjetno najpomembnejši naslednji dejavniki: močan veter, vlažna plitva tla in rob vrzeli. Druga pomembna dejavnika vetroloma sta bila prsni premer in prisotnost trohnobe. Širina in višina krošnje v tem primeru nista bila odločujoča dejavnika vetroloma. Tudi število in debelina korenin v tem primeru zaradi plitke zakoreninjenosti smreke (23 cm +/- 8 cm) in razmočenosti tal nista bila pomembna.

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