

Regeneration of Scots pine *Pinus sylvestris* L. in the Carpathians depends on site fertility

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Abstract. The aim of this work was to determine the biometric features of Scots pine *Pinus sylvestris* L. regeneration in terms of their susceptibility to weather-inflicted damage. We compared the damage between three sites located in the Polish part of the Carpathians: Scots pine planted in (I) fertile sites of mountain broadleaved and mixed broadleaved forest, (II) poor sites of mountain coniferous forest and (III) sites of Scots pine natural refuges during the post-glacial period. In each of the three sites of pine regeneration, 11 research plots were established with 50 pine trees on each plot. For each tree, the following biometric measurements were taken: diameter at breast height, height, 3-year height increment, crown length and crown width measured along the contour line. The Scots pine regeneration was found to vary in terms of their biometric features depending on the site fertility. In fertile sites, the biometric parameters of the trees increased at a faster rate compared to low-fertility sites causing an increase in their susceptibility to damage by adverse weather conditions such as snow and rime. Therefore, the silvicultural risk in fertile sites is high and thus the introduction of pine for regeneration should be avoided in fertile broadleaved and mixed broadleaved forests even if pine provenances from a mountain origin are to be planted. Furthermore, tending cuts in regeneration should be made frequently, but with moderate intensity so as to avoid excessive reductions in tree density. Intensive cuts, especially in fertile sites, promote the expansion of pine crowns, which further increases the risk of damage.

Keywords: mountain region, site conditions, biometric features, damage to trees, damaging agents

1. Introduction

In Poland's mountainous regions, there occur Scots pine *Pinus sylvestris* L. races ('hercyńska' and 'karpacka') that are well adapted to local climate. The 'karpacka' Scots pine occurs in the Tatra Mountains and Pieniny Mountains, as well as in the Kotlina Nowotarska region (the so-called 'Podhale' Scots pine). Dispersed 'mountain' Scots pine sites are situated at an altitude of 750 m a.s.l. in the Beskid Mountains, the Beskid Sądecki Mountains and the Wyspowy Beskid Mountains (the so-called 'wdziarowa' Scots pine) (Staszkievicz 1970).

Scots pine refuges from the post-glacial period, which are reservoirs of the aforesaid 'mountain' pine provenances, occur in the specific mountain habitats with boundary soil moisture conditions (Białobok 1970; Pancer-Kotejowa 1973; Staszkievicz, Szeląg 2003; Urbaniak, Vončina 2008; Kaczka et al. 2012). Calcicolous *Pinus sylvestris* forests of

a relict nature occupy steep slopes with shallow, skeletal soils and rapid rainwater drainage (Pancer-Kotejowa 1973). Swamp forests with Scots pine usually grow within flat areas with a peat ground, situated at the bottom of mountain valleys (Staszkievicz, Szeląg 2003).

Scots pine plantations of mountain provenances have been currently established in the mountainous regions, even in fertile broadleaved and mixed broadleaved forests sites, where several-year-old Scots pine trees show enhanced annual height increment. This may cause their increased susceptibility to weather-inflicted damage. Hence, the question arises whether Scots pine regeneration growing on fertile post-agricultural lands or that artificially introduced onto forest lands is able to retain favourable features of Scots pine mountain provenances. This issue has gained much importance in the context of possible augmentation of Scots pine share in forest stands grown in the mountain and foothill regions, which may be forced by now progressing changes in

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environmental conditions. Currently, the most visible symptom of environmental changes is an increased frequency of extreme weather events with impacts on forest tree species (Van Aalst 2006; Jentsch, Beierkuhnlein 2008; Usbeck et al. 2010; Holtmeier, Broll 2011).

It seems that the main factor limiting the role of Scots pine in the Carpathians is this species susceptibility to mechanical damage associated with extreme weather events (e.g. snow loads, rime and strong winds). This study was undertaken to determine the biometric features affecting tree resistance to weather-inflicted damage in regeneration of Scots pine mountain provenances. The weather-inflicted damages in Scots pine young generation planted within fertile forest sites (broad-leaved forest and mixed broadleaved forest) in the Carpathian Mountains were compared with those in Scots pine regeneration growing on the Carpathian poor coniferous forest sites and Scots pine regeneration in natural refuges from the post-glacial period (with boundary moisture conditions). Evaluation of the extent to which site conditions affect the resistance of Scots pine progenies of mountain provenances ('mountain races') to abiotic damage can help to reduce the silvicultural risk associated with Scots pine regeneration in the mountains.

2. Material and methods

The study was carried out in the years 2016–2018, in the Polish part of the Carpathian Mountains. Not yet managed mountain Scots pine regenerations with specific features, that is comparatively lower growth rates and higher resistance levels to abiotic damage as compared to other Scots pine ecotypes, were examined (Skrzyszewski 2001c). The young trees under the study were those planted compliant with the principles of seed regionalisation (planting material was obtained from seeds of the mountain Scots pine ecotype, Table 1), as well as naturally regenerating mountain Scots pine trees of various age, observed both within protected areas (the national park, nature reserves – established among others to preserve mountain Scots pine ecotypes and their habitats) and in the managed forests in the Kotlina Nowotarska region (the 'Podhale' Scots pine).

Three categories of Scots pine regeneration in the mountains were chosen for further analyses: (I) regeneration in fertile broadleaved and mixed broadleaved forests, (II) regeneration in poor coniferous sites and (III) regeneration in specific (extremely dry or swampy) sites. In each category, 11 study objects were selected (33 objects in total). In each of

Table 1. Seed stands of Scots pine in the Carpathians, based on National Register of Forest Basic Material (<http://semen.bn.l.gov.pl>)

No	Forest District	Forest Subdistrict	Forest Compartment	Geographical coordinates	Altitude a.s.l. [m]	Age [years]
1	Bielsko	Straconka	37 b	19°06'–19°06' E 49°48'–49°48' N	540–680	92
2	Węg. Górka	Zielona	145 b	19°07'–19°07' E 49°37'–49°37' N	450–650	87
3	Węg. Górka	Kamesznica	251 i	18°59'–18°59' E 49°34'–49°34' N	600–600	147
4	Jelesnia	Ślemień	203 d	19°25'–19°25' E 49°45'–49°45' N	575–625	147
5	Sucha	Tarnawa	176 b	21°00'–21°00' E 53°15'–53°15' N	550–550	170
6	Sucha	Welcza	433 b	19°32'–19°32' E 49°39'–49°39' N	650–750	85
7	Sucha	Roztoki	228 a	20°27'–20°27' E 53°44'–53°44' N	625–725	145
8	Myślenice	Toporzysko	501 a	19°47'–19°47' E 49°36'–49°36' N	598–598	122
9	Nowy Targ	Bór	119 g	20°01'–20°01' E 49°27'–49°27' N	600–625	156
10	Nowy Targ	Bór	116 c	20°01'–20°01' E 49°27'–49°27' N	600–625	156
11	Stary Sącz	Chelmiec	336 g	20°36'–20°36' E 49°29'–49°29' N	470–560	120
12	Stary Sącz	Przyszowa	27 c	20°29'–20°29' E 49°33'–49°33' N	410–650	115
13	Nawojowa	Florynka	111 b	21°01'–21°01' E 49°33'–49°33' N	440–520	76
14	Nawojowa	Królowa Górna	28 a	20°52'–20°52' E 49°35'–49°35' N	520–580	76
15	Nawojowa	Królowa Górna	24 a	20°53'–20°53' E 49°35'–49°35' N	620–740	71
16	Lesko	Średnia Wieś	191 b	22°19'–22°19' E 49°24'–49°24' N	385–490	115
17	Ustrzyki Dolne	Leszczowate	58 g	22°31'–22°31' E 49°30'–49°30' N	540–540	101

the objects, test plots were established with randomly selected 50 adjacent trees. The plot perimeter and acreage were determined in each case. Because of site diversity (micro-habitats in the study area) obtainable information on the study sites was verified in the field, with special focus on the test plots.

The test plots were situated in the lower mountain zone (approximately 480–1040 m a.s.l.). The category I plots (fertile broadleaved and mixed broadleaved forest sites) were located in the Forest Districts: Wisła (sub-districts: Czarne, forest division (fd) 8b and Bukowiec, fd 146d); Ujsoły (sub-district Sól, fd 92a, 94b, 104b, 105a, 106a); Piwniczna (sub-districts: Majdan, fd 162c and Jastrzębik, fd 177i, 185c, 186c). The category II plots (coniferous forest sites) were established in the Forest Districts: Wisła (sub-district Malinka, fd 142i); Węgierska Górka (sub-district Sikorzane, fd 177b); Nowy Targ (sub-districts: Bór, fd 118b, d, f, g, 119g and Stańcowa, fd 267a, 268a plus privately owned forests supervised by the State Forests, fd 7l, 15b). The category III plots (Scots pine natural refuges) were established in the Forest District Nowy Targ (sub-district Bór – the Nature Reserve Bór na Czerwonem – two plots, fd 108b, 108f plus supervised private forests, fd 1b, 2a, 16c, d), the Forest District Krościenko (supervised private forests, fd 9cx plus the Nature Reserve Przełom Białki pod Krempachami, fd 2d) and the Pieniński National Park (the Macelowa Góra Protection District, fd 411 – two plots).

The fieldworks on all the study plots included the measurement of Scots pine biometric features, determination of population numbers of admixture tree species to verify the factual tree density on the study plots and evaluation of damages in Scots pine trees under the study.

The measured biometric features of the observed Scots pine trees included the diameter at breast height (DBH), tree height (H), 3-year height increment (Ih3), crown length (Lk) and crown width measured along the contour line (Wk). For each tree examined, damages due to deer (browsing, fraying trees with antlers, bark stripping), snow load and rime (observed both on tree stems and whorls) were quantitatively determined. The numbers of trees infested by insect pests and infected by pathogenic fungi were determined on each study plot. Based on the measurement data, tree slenderness coefficients (H/DBH), tree crown length/tree height ratios (Lk/H) and crown shape coefficients (Lk/Wk) were calculated. On each study plot, tree densities were assessed – main and admixture species combined per hectare (ha).

The final assessment of the site effects on the biometric features of Scots pine regeneration was based on the results of the Kruskal–Wallis test (Statistica 9 software, StatSoft Inc. 2009), carried out with the assumed significance level $\alpha \leq 0.05$. For each of the examined Scots pine regenerations, the Pearson correlation coefficients of the biometric features and the mean snow and rime damage/tree/site were calculated.

3. Biometric features of Scots pine regeneration

Within the Carpathian fertile forest sites, Scots pine young plantations (artificial regeneration) were at the age of 5–13 years (Table 2). On several test plots, natural regeneration of admixture species accompanying Scots pine enhanced high density of the plantation (Table 3). The maximum tree density was 15500 specimen/ha. Nine admixture species were recorded, of which the populations of Norway spruce *Picea abies* (L.) H. Karst, silver birch *Betula pendula* Roth, common aspen *Populus tremula* L. and goat willow *Salix caprea* L. were the most abundant.

Due to a high growth rate in Scots pine regeneration on the fertile forest sites, young trees at the age of 13 years achieved the average DBH of almost 10 cm and their mean height was 6.7 m. The greatest 3-year height increment observed was 222 cm (plot No. 9). Trees growing on the fertile sites produced large crowns (the mean width of almost 1.7 m), which showed a considerable share in the total tree height (the mean crown length/tree height ratio Lk/H calculated for all the fertile forest plots was 0.69). The crowns had an oval, vertically elongated shape. The mean crown shape coefficient Lk/Wk calculated for all the fertile plots was 1.45, and the mean tree slenderness coefficient was 79.

The observed Scots pine trees growing in the Carpathian coniferous forest sites originated both from artificial and natural regeneration. Planted Scots pine trees were 5–8 years old, whereas those naturally regenerating were 5–20 years old, depending on the plot (Table 2). On several plots, young forest density was affected by not only admixture species (Table 3) but also specimens from natural Scots pine regeneration. Naturally regenerating Scots pine trees typically occurred in the groups of various sizes, and their numbers per area units were greater in comparison with Scots pine trees planted following artificial regeneration standards. The growth rate of Scots pine planted on coniferous sites was much lower when compared to that on fertile sites. Even with the presence of 20-year-old Scots pine specimens, all the analysed biometric features (H, DBH, Lk, Wk, Ih3) showed significantly lower mean values (Figure 1a, b, c, d, e) at $p < 0.05$ (Kruskal–Wallis test) when compared to those obtained in fertile sites. Also, the mean values of the coefficients of tree slenderness (H/DBH) and crown shape (Lk/Wk) clearly indicated slender Scots pine trees with narrow crowns, significantly different ($p < 0.05$) in terms of these features from Scots pine trees growing in the fertile forest sites (Figure 1f, h). Nonetheless, the differences found between crown length/tree height ratios (Lk/H) in coniferous and fertile forest sites (Figure 1g) were not statistically significant ($p = 0.2710$).

Scots pine regenerations analysed on the plots established within the refuges of this species were exclusively of natural origin. Depending on the study plot, the tree age ranged con-

Table 2. Mean values of selected biometric features of Scots pine trees on research plots established in regeneration

Plot no	A	N	Dbh [cm]	H [cm]	Ih3 [cm]	Lk [cm]	Wk [cm]	H/Dbh	Lk/H	Lk/Wk
Fertile sites of mountain broadleaved and mixed broadleaved forest										
1	6	9419	1.8	156	123	122	94	97	0.78	1.35
3	8	10833	4.5	315	192	225	145	75	0.70	1.56
6	7	15538	4.3	273	181	200	144	67	0.73	1.42
7	6	14150	3.2	246	158	166	122	83	0.67	1.37
8	8	12000	5.1	356	212	255	180	75	0.71	1.44
9	7	7586	6.3	405	222	304	215	66	0.75	1.46
10	5	6458	1.4	126	92	95	67	104	0.75	1.52
11	8	4301	3.9	265	150	197	150	81	0.72	1.38
12	13	2571	9.9	672	207	392	285	75	0.58	1.49
13	10	5417	6.7	482	204	281	201	78	0.57	1.48
15	11	4880	7.7	529	207	323	244	73	0.61	1.51
Mean		8468	5.0	348	177	233	168	79	0.69	1.45
Poor sites of mountain coniferous forest										
2	8	8400	3.2	225	122	183	118	76	0.80	1.56
4	7	9063	2.5	198	117	162	106	86	0.81	1.54
16	5–15	6538	1.9	216	77	155	78	163	0.71	1.96
17	5–15	19302	2.1	236	90	163	72	161	0.66	2.23
18	5–12	17063	2.2	250	114	170	87	144	0.66	2.14
19	5–12	22462	2.2	240	97	153	84	151	0.59	1.81
20	5–10	13492	1.6	211	69	122	67	183	0.56	1.87
21	5–12	14093	2.9	310	112	199	118	140	0.61	1.69
22	5–10	8443	2.1	230	111	176	91	138	0.75	2.04
23	5	7356	1.2	104	73	86	64	135	0.82	1.37
24	5–20	8125	2.4	218	73	166	88	149	0.74	2.04
Mean		12212	2.2	222	96	158	89	139	0.70	1.84
Sites of Scots pine refuges										
25	10–25	7371	4.3	371	81	233	126	125	0.61	1.82
26	5–20	3810	3.9	342	117	260	125	122	0.72	2.02
27	5–20	3226	4.5	423	94	272	139	121	0.62	1.92
28	10–30	9355	3.8	360	42	208	108	115	0.56	2.02
29	10–30	7969	2.0	181	28	98	72	163	0.52	1.30
30	10–30	6173	2.1	174	47	107	74	139	0.59	1.42

Plot no	Spruce	Birch	Aspen	Willow	Rowan	Beech	Oak	Larch	Fir	Total
21	3560	2967	-	148	-	-	-	-	-	6675
22	925	1735	-	-	-	-	-	-	-	2660
23	1609	-	-	-	-	-	-	-	-	1609
24	-	313	-	-	-	-	-	-	-	313
Total	24009	7084	-	1322	469	1671	133	-	758	35446
Sites of Scots pine refuges										
25	283	-	-	-	-	-	-	-	-	283
26	1008	-	-	-	-	-	-	-	-	1008
27	-	-	-	-	-	-	-	-	-	-
28	1290	-	-	-	-	-	-	-	-	1290
29	156	-	-	-	-	-	-	-	-	156
30	-	-	-	-	-	-	-	-	-	-
31	-	-	-	-	-	-	-	-	-	-
32	-	-	-	-	-	-	-	-	-	-
33	-	-	-	-	-	-	-	-	-	-
34	-	-	-	-	-	-	-	-	-	-
35	-	-	-	-	-	-	-	-	-	-
Total	2737	-	-	-	-	-	-	-	-	2737

siderably (lower age limit: 5–10 years and upper age limit: 20–50 years) (Table 2). The share of admixture species affected regeneration density to a comparatively small extent.

The majority of the plots analysed in Scots pine refuges were free of admixture species, and on the remaining ones there exclusively occurred more than a few Norway spruce specimens (spontaneous admixture) (Table 3). The older Scots pine specimens (50 years old) were included into the calculations for the biometric features; thus in comparison with the examined within the coniferous sites, the mean values of H and DBH were significantly higher ($p = 0.0381$, $p = 0.0006$, respectively) (Figure 1a, b). At the same time, the significantly lower ($p < 0.001$) values of the mean Ih3 indicated comparatively very slow growth of the trees in the relict sites (Figure 1c). When compared to Scots pine trees growing in the coniferous sites, the differences in Lk and Wk) were not significant ($p = 0.0863$, $p = 1.0000$, respectively) (Figure 1d, e). Scots pine trees growing within the refuge sites were as slender (H/DBH) as those in the conife-

rous sites ($p = 1.0000$) (Figure 1f) and built significantly ($p < 0.001$) shorter crowns in relation to the stem length (Lk/H) (Figure 1g). Therefore, their shape was comparatively less elongated (the significantly lower value of the crown shape coefficient, $p < 0.001$) as compared to that of Scots pine trees growing in the coniferous sites (Figure 1h).

Scots pine regeneration in the natural refuges showed significantly ($p < 0.001$) different values of all the analysed parameters (H, DBH, Ih3, Lk, Wk, H/DBH, Lk/H, Lk/Wk) when compared to the trees examined on the fertile forest sites (Figure 1a–h).

4. Damage to Scot pine regeneration

Damage due to many factors was observed on all the studied Scots pine regeneration plots. Damages to biotic factors included those caused by deer (browsing, fraying trees with antlers, bark stripping), pest insect infestations (mainly foliophages) and diseases due to pathogenic fungi (*Gremme-*

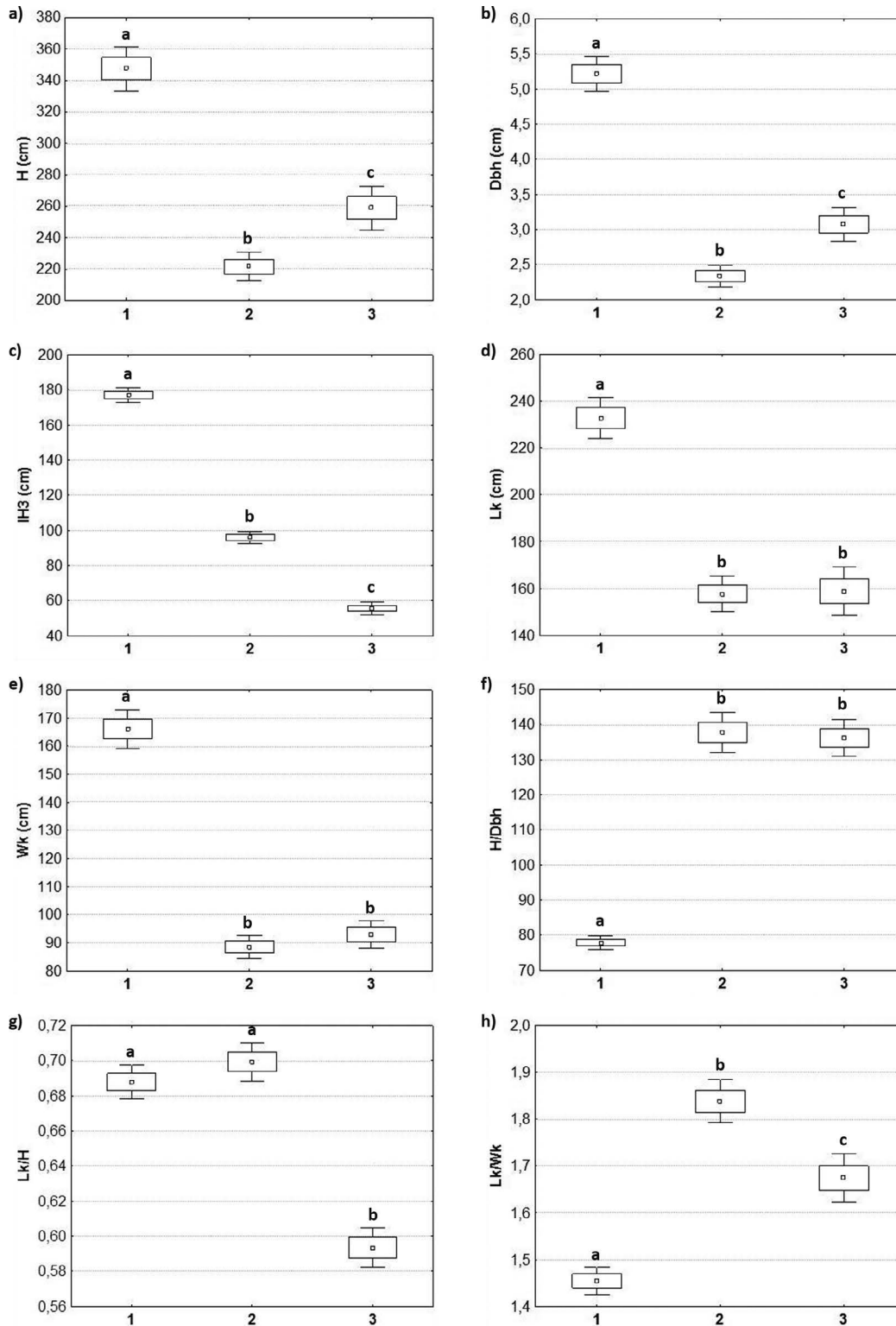


Figure 1. Mean, mean \pm standard error and mean \pm 1.96*standard error of: a) height (H), b) diameter at breast height (Dbh), c) three-year height increment (Ih3), d) crown length (Lk), e) crown width (Wk), f) slenderness coefficient (H/Dbh), g) ratio of the crown length to tree heights (Lk/H), h) coefficient of crown shape (Lk/Wk) of pine regeneration, depending on the site: 1 – fertile sites of mountain broadleaved and mixed broadleaved forest, 2 – poor sites of mountain coniferous forest, 3 – sites of Scots pine natural refuges (different letters indicate significant differences)

niella abietina and *Armillaria* sp.). Abiotic factors included snow loads and rime leading to mechanical damage to the tree top and/or lateral branches. Some trees were damaged due to more than one factor (e.g. deer-damaged stems and snow-broken tops).

The observations conducted on the study plots established within the fertile sites showed a significant number of Scots pine trees infested by pathogenic fungi that caused needle discolouration and drop (59% of the total number of examined trees). Damages due to snow loads and rime were observed on the stems of 34% of the examined trees, and on the side branches – in 31% of trees. Deer damage due to bark stripping was most often observed (13%) (Figure 2). A positive correlation was found between the number of Scots pine whorls broken due to weather impacts and the biometric features of trees, such as DBH, H, Lk and Wk (Table 4). The total number of damages to tree stems and branches as a result of weather factors was positively correlated with tree DBH.

The results obtained in the coniferous sites showed considerable tree damage due to deer (bark stripping – 18% trees). Damages due to snow loads, rime, fungi and insects were less abundant (Figure 2). In the coniferous sites, weather-inclined damage (snow load, rime) correlated with no biometric feature, and the only relationship found was a positive correlation between the number of tree stem damages (as well as stem plus whorl damage in total) and the crown length/tree height ratio (Lk/H) (Table 4).

On the whole, the results of the observations carried out within the Scots pine refuges showed very low damage levels in Scots pine regeneration (a few percent of the total number of the trees under the study) (Figure 2). Damages due to deer were noted (bark stripping – 6% of all the examined trees). Needle discolouration and drop due to fungi infestation were observed in 6% of the total number of trees examined. Weather-inclined damage (snow load, rime) correlated neither with the biometric features nor with the coefficients calculated based on the values obtained during measurements (Table 4).

5. Discussion

The results of this study showed considerable differentiation of the biometric features in not tended mountain Scots pine regeneration in the Carpathian Mountains, depending on the site conditions. The biometric features of Scots pine growing in the Carpathians were previously analysed in older age classes and concerned various provenances of this species (Skrzyszewski 2001a, b, c). The earlier gained knowledge can be supplemented by now presented description of the selected biometric features of Scots pine young generation derived from mountain Scots pine prove-

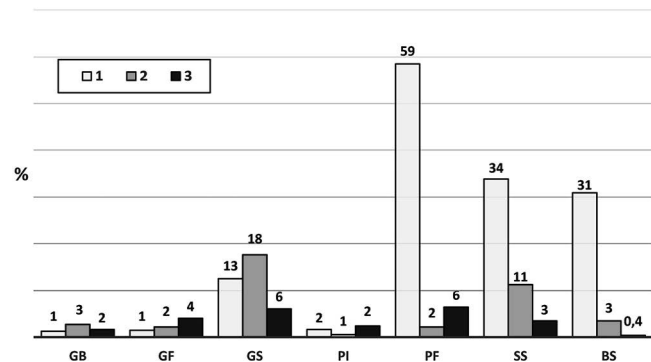


Figure 2. Percentage of trees damaged on research plots located in pine regeneration in fertile sites of mountain broadleaved and mixed broadleaved forest (1), poor sites of mountain coniferous forest (2) and sites of Scots pine natural refuges (3)

(GB – browsing, GF – fraying trees with antlers, GS – bark stripping, PI – damage caused by pest insects, PF – damage caused by pathogenic fungi, SS – stem damage caused by snow or rime, BS – branches damage caused by snow or rime)

nances adapted to the Carpathian conditions. The tendency of developing features less favourable in terms of resistance to weather-inflicted damage, observed in above-mentioned Scots pine older stands growing on fertile forest sites, was confirmed in the case of Scots pine regeneration examined in this study (albeit the trees under the study constituted the progeny of mountain Scots pine provenances).

The ability of young generation to preserve the biometric features favourable in terms of resistance to weather-inflicted damage, observed on other sites tested under the conditions of this study, is particularly important in Scots pine refuges, first of all – for preservation of the continuity of this species in the mountains. The lack of competition of other tree species is also of great importance in the latter sites, especially for young Scots pine trees, which was also confirmed by this study. The results obtained are consistent with those reported by other authors (Pancer-Kotejowa 1973; Skrzyszewski 2001a; Staszkiwicz, Szeląg 2003). The ability of Scots pine to naturally regenerate on poor coniferous sites was proven by Skrzyszewski (2001a); however, as the results of this study showed, in many cases, young Scots pine trees must compete with expansive Norway spruce regeneration.

The considerable weather-inflicted damage observed in regeneration of Scots pine (derived from mountain provenances) within the fertile forest sites was the consequence of the development of less favourable tree biometric features in terms of resistance to snow loads and rime. Damage caused by weather factors to Scots pine in the Carpathians was reported in the second half of the last century, and then it related mainly to Scots pine stands of unknown provenances. At that

Table 4. Value of Pearson correlation coefficients between selected biometric features of trees in regeneration and the number of damage caused by snow and rime per tree (coefficients indicating the existence of correlation have been distinguished)

	Stem damage	Branches damage	Total damage
Fertile sites of mountain broadleaved and mixed broadleaved forest			
H	0.12	0.57	0.45
Dbh	0.31	0.66	0.56
JH3	0.09	0.46	0.36
Lk	0.15	0.53	0.43
Wk	0.17	0.54	0.48
H/Dbh	-0.12	-0.45	-0.36
Lk/H	0.30	-0.26	0.01
Lk/Wk	-0.15	-0.14	-0.21
Poor sites of mountain coniferous forest			
H	0.04	0.03	0.05
Dbh	0.17	-0.09	0.13
JH3	0.09	0.14	0.16
Lk	0.13	0.05	0.14
Wk	0.22	0.13	0.26
H/Dbh	-0.38	-0.25	-0.43
Lk/H	0.61	0.35	0.65
Lk/Wk	-0.24	-0.18	-0.28
Sites of Scots pine refuges			
H	0.24	0.04	0.24
Dbh	0.22	-0.01	0.21
JH3	0.04	-0.07	0.02
Lk	0.20	-0.01	0.18
Wk	0.24	0.05	0.24
H/Dbh	-0.22	-0.09	-0.24
Lk/H	-0.14	0.07	-0.14
Lk/Wk	0.24	-0.06	0.22

(H – height, Dbh – diameter at breast height, Jh3 – three-year height increment, Lk – crown length, Wk – crown width measured along the contour line, H/Dbh – slenderness coefficient, Lk/H – ratio of the crown length to tree heights, Lk/Wk – coefficient of crown shape)

time, the damage was disastrously severe and mainly caused by rime. Nonetheless, the stands were damaged at a local level, in the southern parts of the Beskid Niski Mountains, for the most part on mountain ridges located near the passes (Capecki 1996, 1999; Ambroży 2007). Scattered damage to Scots pine trees due to strong winds or snow loads increased with altitude (Przybylska, Kucharzyk 1999; Przybylska, Zięba 2001; Zięba 2004). Skrzyszewski (2001c) noticed an increase of the silvicultural risk in older mountain and sub-mountain Scots pine plantations established on fertile forest sites. This study indicated that this risk was posed to the youngest developmental stages of Scots pine growing within the fertile sites examined. Weakened trees are susceptible to fungal infections and infestations by harmful insects (Nykänen et al. 1997). Crown damage leads to increased light access to the lower vegetation layers. This can initiate a number of processes important in view of silvicultural practice – from weed expansion to transformation of stand species composition (Kint 2005; Kint et al. 2006; Harmer, Morgan 2009).

The susceptibility of Scots pine regeneration to *Gremmeniella abietina* infection, observed in the fertile mountain sites, was not only a result of the weakening of injured trees. As demonstrated by Niemelä et al. (2008), there is a relationship between stand density and fungal diseases followed by tree mortality. The sensitivity of Scots pine to *Gremmeniella abietina* increases in high-density stands, where lower crown parts are more and more shaded, which is followed by changes of microclimate and humidity conditions more favourable for pathogen spreading. When growing within fertile forest sites, Scots pine trees reach larger sizes comparatively faster and build compact stands, which both provide favourable conditions for the development of fungal diseases (Zachara 2006; Jagodziński, Oleksyn 2009; Gil 2014).

The susceptibility of Scots pine trees growing in the fertile mountain sites to damage due to snow load and rime, increasing with the plantation age, invites consideration of a possibility to shape tree resistance to weather-inclined damage through the use of appropriate management treatments. As far as Scots pine is concerned, it has been generally believed that low stand densities have beneficial effects on tree resistance to snow damage; however this approach fails in many cases (Abetz 1976; Johann 1981; Slodičák 1995). Under the conditions of low stand density, Scots pine crowns tend to expand sideways, which increases the risk of weather-inclined damage. On the contrary, in the case of Norway spruce low stand density supports the increase of the crown/tree height ratio, which results in lowering tree centre of gravity and, thus, improves tree stability (Slodičák 1995). Skrzyszewski (2001c) recommends maintaining compact density in the initial stages of Scots pine stand growth. On the other hand, however, allowing for high density of Scots pine plantations for too long

increases the risk of significant weather-inclined damage, especially in the event of sudden interruption of stand density due to natural reasons or as a result of improperly performed forest management activities (Nykänen et al. 1997). Hence, moderate tending treatments should be performed in Scots pine regenerations, especially those profusely growing on fertile forest sites in the mountains.

Scots pine silviculture in the mountains is not free from the risks associated with weather-inclined damage. Likewise, Scots pine in lowland locations is at risk associated with climate change impacts (Orzechowski, Wójcik 2014). Nevertheless, silviculture of this species has not been given up in Poland's lowland regions, and this decision is justified by site conditions (Sokołowski et al. 1997). In general, forest-forming species in the Carpathian Mountains are subject to damage due to weather conditions, and this mainly concerns Norway spruce (Holuša et al. 2010). In this case, the prolonged periods of water shortages during the growing season (one of the climate change impacts) are particularly severe (Flannigan et al. 2000, Soja et al. 2007). In the recent decades, weather events have become, among others, the cause of Norway spruce growth decline and increased mortality, followed by disintegration of Norway spruce stands in the Beskid Mountains (Grodzki 2007). There has been also observed deterioration of silver fir stands. This species prefers sites with stable and relatively high soil moisture (Jaworski, Zarzycki 1983). The observed effects may indicate changes in mountain site conditions, unfavourable for Norway spruce and silver fir, however suitable enough for Scots pine that is relatively less vulnerable to water stress.

6. Conclusions

1. In the Carpathian Mountains, the progenies of Scots pine mountain provenances are differentiated in terms of the biometric features, depending on the fertility of the site. Within the fertile forest sites, growth parameter values achieved by young trees are in connection with increased susceptibility to stem and branch damage by adverse weather conditions (snow, rime).

2. A considerably large crown size achieved by Scots pine trees growing in the sites of mountain broadleaved forest and mixed broadleaved forest results in a substantial risk of tree damage due to snow and rime – much higher compared to that observed within the coniferous forest and Scots pine natural sites characterised by boundary moisture conditions.

3. On the fertile forest sites, Scots pine regeneration achieves high stand density relatively quickly, which is conducive to young tree susceptibility to infection by the fungus *Gremmeniella abietina*, whose occurrence here is many times higher than that in the coniferous sites and Scots pine natural refuges.

4. In the fertile mountain forest sites, the risk of damage due to adverse weather conditions increases with Scots pine growth and crown expansion, which significantly increases the silvicultural risk when compared to that posed to Scots pine regeneration in other site categories studied.

5. Because of the high silvicultural risk, it is necessary to avoid planting Scots pine within mountain broadleaved forest and mixed broadleaved forest sites, as well as on former agricultural lands as the preceding crop, even if the seedlings originate from mountain provenances of this species.

6. Scots pine regeneration should be treated with frequently repeated tending cuts of moderate intensity. Stand density should not be excessively decreased – especially within the fertile forest sites – so as to avoid enhanced expansion of Scots pine crowns and increased risk of damage caused by adverse weather factors. During tending treatments attention should be paid to limiting the expansion of tree species competing with Scots pine, mainly Norway spruce, birch, aspen and willow.

Conflict of interest

The authors declare no potential conflicts.

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Authors' contribution

S.A. contributed to manuscript concept, fieldwork, production of the results and manuscript writing. M. K. helped in fieldwork and statistical analyses.