

## Article

# The Effect of Bark Stripping by Deer (*Cervus elaphus* L.) on Biometric Parameters of the Scots Pine (*Pinus sylvestris* L.)

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**Abstract:** Bark stripping by red deer (*Cervus elaphus* L.) is one of the most acute instances of damage wrought by these animals in a forest. Because of its location, bark stripping causes damage to the thickest and most valuable part of the tree trunk, which lowers the quality of the wood due to technical flaws. The research was conducted in 25 sampling sites of pine stands aged 35 years in a mixed, fresh forest habitat in south-western Poland. The study was aimed at assessing the influence of bark damage by deer on biometric parameters of pine stands (*Pinus sylvestris* L.). The assessment involved the diameter at breast height, height, basal area and volume of the tree stands. The results revealed a strong deer-specific pressure on the analysed pine stands. The share of bark stripped trees ranged from 65% to 96%. The number of bark damage instances (NBDI) on a given tree was found to significantly affect its diameter at breast height. The strip-damaged trees had breast height diameters lower by 23% on average, and their mean height was lower by 8.7% as compared with the trees without damage. The mean reduction in basal area increments ( $G_{1,3}$ ) of the trees was identified at 39%. In a similar way to the diameter at breast height and the basal area, the losses in tree stand volume growth caused by deer stripping were significant and oscillated at 41%.

**Keywords:** bark stripping; damage; deer; DBH; basal area; stand volume; *Pinus sylvestris* L.



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## 1. Introduction

The increase in the range and population density of large wild ungulate animals has been documented over the last century in many European countries [1–10] and other parts of the world [11–13]. The increased population density often leads to losses in crops [14] and tree stands [15,16]. The presence of red deer (*Cervus elaphus* L.) in commercially forested areas can cause considerable conflict between forestry interests and wildlife management because red deer can severely damage forest stands by browsing and bark stripping [17–20].

Bark stripping is primarily determined by ruminant dietary physiology. Ruminant energy requirements change depending on the phenological season, atmospheric conditions and the age and physiological condition of cervids [21–23]. In a summer month, deer require between 16 kg and 17 kg of green provender in their diet [24], with the animals feeding on 256 plant species [21]. This diversity results from the fact that the animal intuitively consumes plants that supplement its demand on proteins, carbohydrates, fats and micro- and macro-elements in a given period [25]. The digested leaves, shoots and young unlignified bark provide natural food for cervids. They have a high nutritive value and complement coarse fibre components, which explains their consumption by deer, especially in periods of poor access to food [22,25–34]. Studies containing seasonal data

show that the bark constitutes more than 10% of food consumption during the winter period (between December and March) [32]. Wajdzik et al. [35] calculated that the winter demand of deer on the bark ranges from 55 kg to 77 kg of dry mass. Analyses of the cervid diet also reveal a correlation between an elevated share of young grasses and herbs in the deer diet and the simultaneously increasing number of tree stripping instances [36]. Unfortunately, the specific dietary requirements of cervids are not taken into account in winter food supplementation, which may lead to damage aggravation. The animals, provided with additional food by hunters, predominantly with juicy and strengthening fodder, balance their food intake by consuming larger amounts of fibre contained in the bark. This allows them to maintain a balanced pH value [17], large active surface and access for the enzymes to the food content in the rumen [23]. The supply of more balanced food in a comprehensive feeding programme could decrease the extent of bark stripping [37]. The deer also consume bark because of its antiparasitic effects [17,32]. The stress stemming from the anxiety felt by the animals during rumination causes disadvantageous physiological changes to appear, leading to rumen acidosis. The animals often react by consuming fibre-rich food in such situations. This was confirmed in Belgian studies, which showed intensified tree stripping by deer previously startled when ruminating [22]. The factors that contribute to increased stripping include the tree stand composition and structure and high density of the deer population [17]. There are 282,000 deer (*Cervus elaphus* L.) in Poland's forests, which cover about 8 million hectares [38].

One of the most severe instances of damage caused by deer in a forest is bark stripping. Coniferous trees are more affected by bark stripping than broad-leaved trees [15]. The consequences of bark stripping are closely linked to the tree's specific sensitivity to pathogens once the wood has been deprived of its protective bark [33]. Debarking lesions are difficult to heal on trees, and the process can take up to 30 years [39]. The healing over of pine bark damage is not completed with calluses but through sealing. The edges of the wound gradually converge due to annual growth, eventually covering it [39]. Damage to the bark is not always completely sealed. The axis trunk at the stripping damage height remains asymmetric, which causes a shift in the tree axis, with a visible ovality of the trunk. Moreover, technical defects, such as rind galls or bark pockets, may appear in pinewood as a result of bark stripping. The wounds can also be infected with parasitic fungi [17,32,40–43]. The fungi invade the inner part of the stem and usually develop a typical heartrot that expands to 0.5–8.3 m of the stem length [44], which in the future will degrade the technical quality of the wood [17,41,45–47]. Due to the low position of the bark damage, technical defects of wood concern the thickest, and therefore the most valuable part of the trunk [44], and the associated reduction in usable timber quantity and quality causes a 20–30% decrease in timber revenue [48]. Due to decreased resistance to both biotic and abiotic factors, widespread damage to numerous trees can result in the disintegration of an entire tree stand [49]. If more than 90% of the trunk perimeter is stripped, the whole tree normally decays [50]. Damaged tree stands lose stability, are more vulnerable to wind and snow and, thus, have reduced ability to perform their ecological and environmental functions [14,51–54]. Effects of such additional consequences can be devastating for stands in areas where the damage is concentrated—for example, in the former Czechoslovakia, this resulted in the loss of 400,000 m<sup>3</sup> of woody mass per year [55]. The assessment of the bark stripping effect crucially considers the time during which bark stripping takes place, the size of damaged trunks, the frequency of repeated damage and the sealing (healing) of lesions [41].

The study was aimed at assessing the influence of bark damage by red deer on biometric parameters of 35-year-old pine stands (*Pinus sylvestris* L.). The assessment included the diameter at breast height, height, basal area and volume of the damaged and undamaged trees. Stripping-associated economic losses connected with tree growth were analysed. It was analysed how the number of bark damage instances affected the productive parameters of tree stands. The problem of bark damage is not a new question in the literature. A lot of information can be found on the effect of bark damage on the

European spruce. On the other hand, there are much fewer data on the impact of pine bark damage, and what is known mostly pertains to younger tree stands. It seems reasonable since it is commonly thought that bark damage does not cause such extensive damage on pines as on spruces. Secondly, it is assumed that bark stripped trees will be removed during sanitarian and intermediate cutting. We conduct field research in an area with significant deer pressure on the forest ecosystems and express the effects of deer feeding in parameters that describe tree damage resulting from deer activity in the habitat.

## 2. Materials and Methods

### 2.1. Description of the Study Site

The analyses concerned single-species and even-aged stands of the Scots pine (*Pinus sylvestris* L.) in south-western Poland (extreme incidence coordinates: 50°32' N; 17°42' E–50°45' N; 17°44' E). Currently, 11,600 deer live in a forested area of 211,000 ha [38]. The compact forest complex we are analysing, called “Bory Niemodlińskie”, covers approximately a quarter of this area and is currently administered by three forest districts: Opole, Prószków and Tułowice [56–58]. Herds of deer are free to move from one forest complex to another. Depending on the duration of the winter period, the demand of deer on shoot fodder ranges from 638,000 to 899,000 kg of dry matter.

In accordance with forest management plans [56–58], the analysed pine stands were of the same age (35 years) and located in a fresh mixed forest habitat. The habitat quality indicators (1st class of habitat valuation) and soil type (podsolc soil) were identical in all the sites. The sites were situated on flat land ranging from 156 to 220 m a.s.l. in height. The mean total of precipitation amounted to 635 mm·year<sup>-1</sup>, with the heaviest precipitation recorded in July (91 mm max) and the lowest in February (30 mm). The duration of snow cover presence fluctuated between 50 and 70 days per year, with the mean thickness ranging from 5 to 15 centimetres. The average annual temperature was 8.5 °C. July was the warmest (18.1 °C) and January the coolest (−1.2 °C). The growing season lasted for −248 days [56–58].

The ground cover contains: *Molinia caerulea* L., *Deschampsia flexuosa* L., *Pteridium aquilinum* L., *Melampyrum pratense* L., *Vaccinium myrtillus* L., intermittently *Vaccinium vitis-idaea* L., and *Calluna vulgaris* L. The mossy and lichenous layers on the analysed sampling sites are represented by *Entodon schreberi* Mönk., *Hylocomium splendens* Hedw., *Leucobryum glaucum* Hedw. and *Parmelia sulcata* Taylor.

### 2.2. Field Measurements

Twenty-five sampling sites, measuring 100 m<sup>2</sup> (10 × 10 m), were designated. The sites were established within compartments at least 25 m away from the compartment line. The selected experimental plots met four basic criteria. First, the stands were present in the same habitat type and under comparable climatic conditions (temperature, precipitation). They were single-species pine stands after maintenance treatment. Moreover, the age of the pine trees (35 years) was identical in all the plots.

The diameter at breast height (DBH) (at the height of 1.3 m) and the height (H) were measured for all 630 trees in early spring (March), prior to the start of vegetation, in all the experimental sites. The diameter at breast height was measured exact to 1 mm with a metal Mantax Blue tree calliper (Haglöf, Långsele, Västernorrland, Sweden). When measuring the diameters at breast height, each tree was precisely checked to record damages and the number of bark damage instances (NBDI) on a given tree caused by bark stripping. The heights of the trees were measured with a Vertex III height finder (Haglöf, Sweden).

The following biometric parameters were analysed: the diameter at breast height (DBH), the height (H), the basal area of the stand ( $G_{1.3}$ ), the mean basal area of the trees ( $g_{1.3}$ ), the stand volume ( $V$ ) and the mean tree volume ( $v$ ).

### 2.3. Statistical Analysis

Statistical calculations were performed in an R language environment [59]. Most functions used were available in the basic R. The coherence of two distributions was

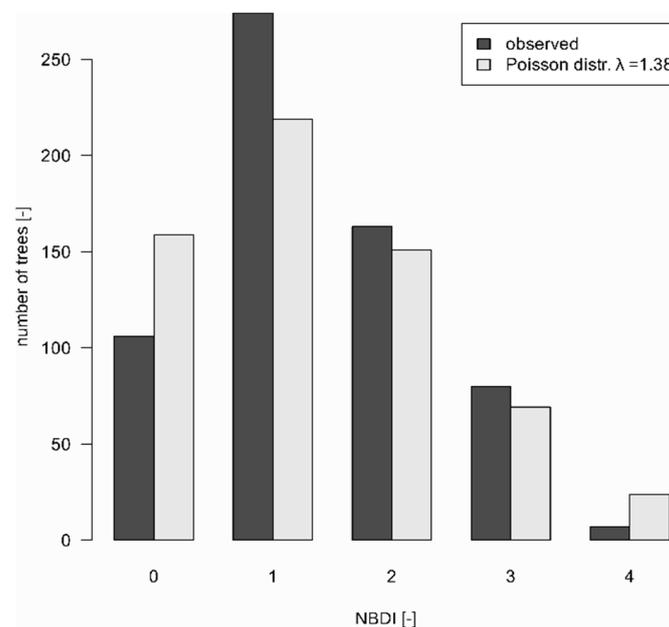
verified using the Kolmogorov–Smirnov test. Shapiro–Francia, Anderson–Darling, and Cramer–von Mises tests were used for the verification of data distribution normality [60]. Functions from the R package “nortest” were used in the calculations [61]. The Breusch–Pagan test was used for the heteroskedasticity verification of the linear model [62]. The critical  $p$ -value ( $p_{cr}$ ) for the test, resulting in null hypothesis rejection, was 0.05.

### 3. Results

#### 3.1. The Correlation between the Diameter at Breast Height and the Number of Bark Damage Instances on the Tree

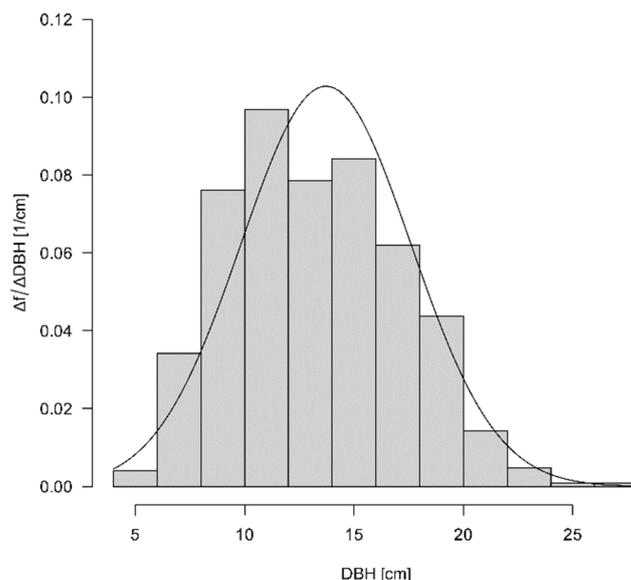
The pine stands under analysis had different densities, ranging from 1800 trees·ha<sup>-1</sup> to 3900 trees·ha<sup>-1</sup> (a difference of 46%). The diameter at breast height ranged between 5 and 27 cm. The analysis of the percentage share of the bark damage instances in the investigated tree stands revealed that the stripping in all the experimental sites was a mass phenomenon. The bark stripped pines constituted 65–96 % of the analysed single-species pine stands. The instances of bark damage were located at a height between 1.0 and 2.6 m from the ground and their lengths ranged from 40 to 70 cm. Spearman’s correlation coefficient between the trees’ density on the plot and the number of bark stripping trees is  $r = 0.92$  ( $p < p_{cr}$ ). On the other hand, the correlation coefficient between the density of trees on the plot and the NBDI is  $r = 0.81$  ( $p < p_{cr}$ ).

The bark damage observed on the trees did not exceed four instances. The Poisson distribution with  $\lambda = 1.38$  was used for the description of the observed NBDI (Figure 1). The Kolmogorov–Smirnov test was applied to verify the coherence of the theoretical and empirical distributions. The calculated  $p$ -value was bigger than the critical  $p_{cr}$ , confirming the consistency of both distributions.



**Figure 1.** Tree numbers observed (black bars) and calculated from the Poisson distribution (grey bars,  $\lambda = 1.38$ ) with {0..4} damage instances.

The distribution of DBH is unimodal and approximately symmetric. The contour of the distribution indicates normal distribution of the data. Figure 2 shows the histogram of DBH distribution and a curve representing the density of the normal distribution (for a mean = 13.7 and SD = 3.9).



**Figure 2.** Distribution of all the tree diameters at breast height.

A line representing the density of the normal distribution seems to adequately describe the histogram of the DBH observations. Shapiro–Francia, Anderson–Darling, and Cramer–von Mises tests were used for the evaluation of DBH distribution normality. The calculated  $p$ -values were orders of magnitude lower than the critical  $p_{cr}$ . Rejection of the null hypothesis regarding the DBH distribution normality was clear.

Uniformity of NBDI and DBH distribution with respect to the 25 sampling areas identified with factor variable ID was evaluated. The generalised linear model (GLM) with Poisson error distribution was used for testing NBDI dependence on ID [63,64]. The model formula was:

$$\text{NBDI} \sim \text{ID}$$

i.e., NBDI depends linearly on ID.

The  $p$ -values of the structural parameters corresponding to the individual IDs were bigger than the  $p_{cr}$ . No evidence for the influence of the area ID on average NBDI was found.

The distribution of DBH was non-normal. An ANOVA model DBH–ID for the comparison of means produced non-normal residuals impairing  $p$ -value interpretation. The pairwise Wilcoxon rank sum test was used for testing the homogeneity in location parameters of the DBH observations in the different areas. The observation results collected in the areas under analysis were compared with one another. The Benjamini and Hochberg method was used for  $p$ -value adjustment with respect to multiple comparisons [65]. No significant shift in DBH distributions for pairs of areas was identified. To evaluate an effect of both ID and DBH on NBDI models, NBDI–ID + DBH with Poisson and binomial error distribution were assessed. In both models the  $p$ -values corresponding to DBH structural parameters were lower than  $p_{cr}$ . Conversely, for all levels of ID the related  $p$ -values were higher than  $p_{cr}$ .

The analysis of the data concerning the observed areas indicates homogenous distribution of the basic statistical properties. The influence of ID on the variables can be ignored.

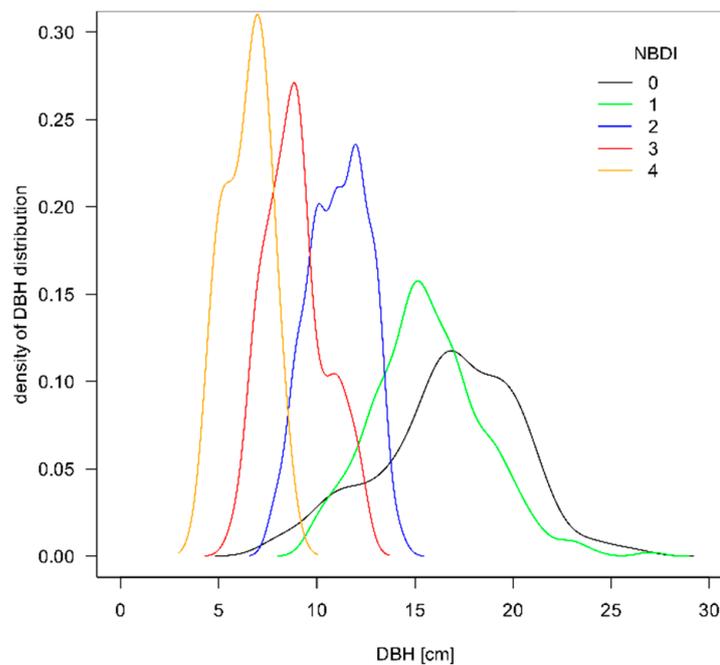
Only 16.8% of the trees at all the sites were undamaged. The majority of the damage to the trees was limited to one (43.5%) or two (24.9%) instances. Trees with three instances of bark damage made up 12.7% of the total, and sporadically, some trees had four instances (1.1%). The influence of NBDI on DBH was investigated. Table 1 shows the statistical parameters of DBH for different NBDI.

**Table 1.** The values of minimum, arithmetic mean, median, maximum, standard deviation (SD) and median absolute deviation (MAD) were calculated from DBH for different NBDI.

NBDI [-]	DBH [cm]						Number of Trees [pcs]
	Min	Mean	Median	Max	SD	MAD	
0	8	16.8	17	26	3.6	3.0	106
1	10	15.7	15	27	2.8	3.0	274
2	8	11.1	11	14	1.5	1.5	163
3	6	8.9	9	12	1.5	1.5	80
4	5	6.4	7	8	1.1	1.5	7

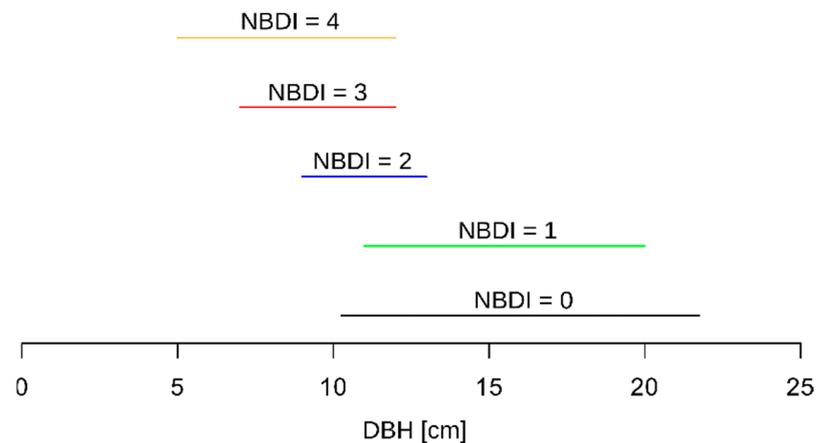
NBDI—number of bark damage instances; DBH—diameter at breast height.

Similar means and medians for the NBDI: {0..4}, indicate no outlying observations. This assertion is supported by similar SD and MAD values. The general tendency shows a decrease in the parameter values corresponding with an increase in NBDI. Figure 3 depicts density plots illustrating distributions of DBH for respective NBDI. The distributions are unimodal, with decreasing positions of maximum and variability along with increasing NBDI.



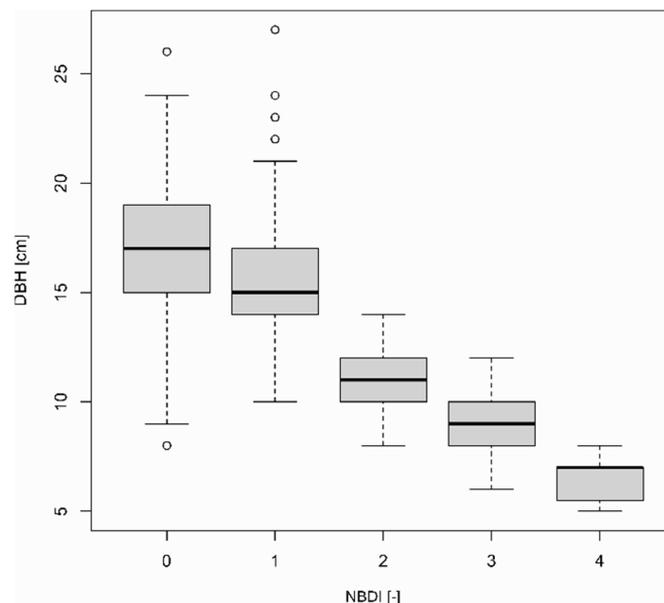
**Figure 3.** Density of diameter breast height (DBH) distribution in relation to the number of bark damage instances (NBDI) on the tree.

Figure 4 shows positions of the ranges that limit 90% of the most frequent DBH values. Five percent tails of the lowest and highest values were cut to illustrate the most common values of DBH. A shift of the ranges toward lower DBH values and a decrease in their length along with an increase in NBDI were observed. A clear exception is the range for NBDI = 4. Low numbers of observations used in the calculations may be the cause of the range that is wider than expected.



**Figure 4.** The 95% confidence intervals for the DBH means for trees with {0..4} instances of bark stripping damage.

The influence of NBDI on DBH changes was studied. Figure 5 contains boxplots representing DBH distribution for different NBDI. The positions of boxes in the plot suggest a monotonical decrease in DBH along with increasing NBDI.



**Figure 5.** Median (horizontal line in box), the 25th percentile to the 75th percentile (box spans) and a ‘whisker’ ranging to maximum and minimum but no more than 1.5 times of the interquartile range (IQR) from the box top and bottom, respectively.

Because distributions of both variables were different, the Spearman correlation coefficient  $\rho$  and its  $p$ -value were calculated for co-variability assessment. The calculated  $\rho = -0.748$  ( $p$ -value  $\ll p_{cr}$ ) indicated a decrease in DBH along with increasing NBDI. A linear model was applied for DBH description using the NBDI parameter. The calculated slope was  $-2.98$  and the intercept was  $17.8$ . The corresponding  $p$ -values for both coefficients were orders of magnitude lower than  $p_{cr}$ .

The conclusion from the subsequent analysis of the model is that it can be regarded only as a rough estimation of the real DBH dependence on the NBDI. The model does not accomplish homoskedasticity (verified with the Breusch–Pagan test against heteroskedasticity,  $p$ -value  $\ll p_{cr}$ ) and normal distribution of the model residuals (tests for normality,  $p$ -value  $\ll p_{cr}$ ).

### 3.2. The Basal Area and Volume of the Tree Stand

The measured dendrometric data, i.e., DBH and H, were used to calculate the basal area ( $g_{1.3}$ ) and volume ( $v$ ) of the trees. The comparison of the mean values for the bark stripped and non-stripped trees is presented in Table 2. The Mann–Whitney test applied for shift  $\mu$  for DBH distributions in both groups of trees indicates rejection of  $H_0: \mu = 0$  ( $p$ -value  $\ll p_{cr}$ ). The estimated  $\mu$  is 4 and the 95 percent confidence interval is limited in the range from 3 to 5. The mean diameter at breast height of the undamaged trees was 4 cm larger than that of the stripped ones. This was reflected in the mean  $g_{1.3}$ . The mean  $g_{1.3}$  for the trees without bark damage is  $0.0246 \text{ m}^2$ , whereas it is  $0.0149 \text{ m}^2$  for trees that have had their bark stripped. The losses in volume caused by deer stripping are significant at a 41% rate. Likewise, considerable losses of 39% were recorded for  $g_{1.3}$ .

**Table 2.** Mean values of the biometric parameters for trees with or without bark damage.

Number of Plots	The Undamaged Tree				The Damaged Tree (Bark Stripped)			
	DBH [cm]	H [m]	$g_{1.3}$ [m <sup>2</sup> ]	$v$ [m <sup>3</sup> ]	DBH [cm]	H [m]	$g_{1.3}$ [m <sup>2</sup> ]	$v$ [m <sup>3</sup> ]
1–25	17.3	16.0	0.0246	0.167	13.3	14.6	0.0149	0.099

The volumes of the tree stands at different densities were analysed. Table 3 juxtaposes the percentage shares of damaged and undamaged trees along with their volumes.

**Table 3.** The percentage shares of damaged and undamaged trees along with their volumes.

No. Plots	Total Number of Trees	% of the Number Undamaged Trees	% of the Number Damaged Trees	Volume of Undamaged Trees (V)	Volume of Damaged Trees (V)	Total Volume (V)
	[Trees·ha <sup>-1</sup> ]	[%]	[%]	[m <sup>3</sup> ·ha <sup>-1</sup> ]	[m <sup>3</sup> ·ha <sup>-1</sup> ]	[m <sup>3</sup> ·ha <sup>-1</sup> ]
1	2500	16.0	84.0	55.8	194.2	250.0
2	2800	10.7	89.3	39.0	237.7	276.7
3	2100	28.6	71.4	113.0	175.3	288.3
4	2500	16.0	84.0	81.9	202.7	284.6
5	2600	15.4	84.6	82.6	192.1	274.8
6	2000	25.0	75.0	97.1	164.8	261.9
7	1900	21.1	79.0	107.2	150.3	257.5
8	2100	23.8	76.2	86.4	183.1	269.4
9	3000	20.0	80.0	94.1	175.7	269.8
10	3400	11.8	88.2	43.2	248.7	292.0
11	3900	10.3	89.7	36.9	280.5	317.5
12	2000	5.0	95.0	43.5	190.7	234.1
13	3000	23.3	76.7	114.1	212.3	326.3
14	2800	10.7	89.3	66.0	264.1	330.1
15	2200	4.6	95.5	26.5	257.0	283.4
16	2400	25.0	75.0	75.4	130.8	206.2
17	3100	9.7	90.3	54.7	242.5	297.2
18	2600	11.5	88.5	79.6	171.9	251.5
19	2400	25.0	75.0	101.5	212.4	313.9
20	2700	3.7	96.3	14.3	306.4	320.7
21	2200	18.2	81.8	44.8	183.3	228.1
22	2300	17.4	82.6	52.1	245.3	297.4
23	1800	22.2	77.8	52.5	225.5	278.0
24	2000	35.0	65.0	133.5	145.7	279.3
25	2700	29.6	70.4	91.4	187.0	278.4

In this study, 77.8% of damaged trees were identified at the lowest density of 1800 trees·ha<sup>-1</sup>. On the other hand, the tree stands with the highest density of 3900 trees·ha<sup>-1</sup> contained 89.7% of damaged trees. The highest percentage of damaged

trees (96.3%) was identified in the plot with tree stands density of 2700 trees·ha<sup>-1</sup>. The volumes of large timber damaged by deer in 25 experimental fields ranged from 131 m<sup>3</sup>·ha<sup>-1</sup> to 306 m<sup>3</sup>·ha<sup>-1</sup>, which amounts to 74.4% on average. Only 25.6 % of the obtained volume did not bear vestiges of damage by deer. Obviously, it is not certain to what extent the recorded damage will ultimately impinge on the timber assortment collected during the cutting period. It is unknown what part of the assortment will have technical defects. However, the results suggest the scale of damage is high, with considerable losses in volume growth.

#### 4. Discussion

The Scots pine is the most common and, at the same time, the most important forest-forming species in Poland. It has crucial economic and natural importance. The Scots pine extends over almost the entire area of this country. It makes up 62% of the growing stock and 60% of the species composition of forests [38]. The high percentage share of the pine results from habitat conditions [66]. The forest assessment conducted between 2017 and 2021 revealed that more than 102,000 ha of Polish forests were damaged by animals [67]. Debarking is observed in many tree species, but the pine domination determines the use of pines by animals as the principal fodder source, which leads to the appearance of this damage. Pine stands constitute almost 53% of all the damaged tree stands, with 4% of damage caused by animals [67].

The present study clearly shows tree stripping is common in the analysed area and affects the productive parameters. There are numerous and severe instances of damage to the tree trunks. The bark damage is well sealed over on most trees (Figure 6a). The technical defects in the most valuable lower part of the axis trunk will, in turn, be revealed only after felling. This will ultimately result in a lower quality of the obtained timber (Figure 6b). The identified high share of debarked trees, at over 65% (Table 3), is the consequence of damage made in the sapling stand stage. Previous research [68,69] conducted in sapling stands aged 8, 12, 14, 16 and 20 years revealed the scale of the problem. The share of trees with bark damage ranged from 72% to 96%. The axis trunk was most often damaged at 50–150 cm from the ground, between the second and third whorl [69]. Summer bark damage has more acute consequences than winter stripping. The wounds tend to be deeper and involve not only the bark but also the phloem and the woody part, and the bark can be more easily separated from the trunk.



**Figure 6.** Bark stripping wound on stem of *p. sylvestris*. (a) 30-year-old bark stripping wound, (b) cross-section of an old bark stripping wound that showed stem deformation.

The effects of bark damage in the analysed second age class tree stands are reflected in the biometric parameters of the damaged trees. The debarked trees have an average of 23% lower DBH as compared with undamaged trees (Table 2). Similar observations were made by other authors in tree stands of comparable ages [32,70]. On the other hand, an inverse correlation is noticed in younger tree stands [68,71]. The debarked trees have higher biometric parameters. This makes sense because the animals choose to strip the trees that are already large enough to provide resistance during consumption. Therefore, the damaged trees are thicker and slightly taller than those without damage. This applies to the youngest tree stands [68,71]. For example, the mean diameter at breast height of 7-year-old pines with bark damage was 3.4 cm, while that of undamaged trees was 5.8 cm [71]. An analogous relationship was documented for 8-year-old pines (4.7 cm and 4 cm), 72% of which were debarked [69]. Due to the scant numbers of undamaged trees, only information on the diameter at breast height of stripped trees is available in studies of older sapling stands. The greatest extent of damage was identified in the 12-year-old tree stand, where 96% of the trees were debarked and their mean DBH was 4.5 cm. The 20-year-old pine sapling stand contained as many as 94% of damaged trees, with their DBH amounting to 8.7 cm [68]. With such extensive damage, it is clear that only stripped trees remain available for further cultivation after maintenance. This explains the high shares of damaged trees recorded in 35-year-old stands (Table 3), and their diameters at breast height clearly show a decline in radial growth depending on the NBDI (Figure 5). The mean DBH is reduced from 15.7 cm with one damage instance to 6.4 cm with four damage instances (Table 1).

The losses in height increments of the damaged trees are far lower than in the case of the diameter at breast height and amount to 8.6% as compared with the undamaged trees (Table 2). A similar observation was made by Cukor et al. [70], who noticed that older pine stands (aged between 40 and 42 years) do not show significant differences in height between healthy and debarked trees. Lichtenwatd [72] concluded that a significant deceleration in height growth occurs in the first year following debarking, with the growth mostly returning to normal after the third year. Szczerbiński [73] claims that the deceleration in height growth is noticed up to a maximum of 5 years after debarking. Finish studies show the height development of the European spruce axis trunk diminished by ca. 15% [74]. Pach's research [75], on the other hand, confirms debarking causes an average deceleration of the growth in pines by 12%. The 7-year-old pine sapling stand manifested height increments decelerated by 14% in relation to the undamaged trees [71].

The mean damage-induced growth reduction in  $G_{1,3}$  of the analysed tree stands was 39%. Ebiś [76] reports  $G_{1,3}$  diminished by 20% through bark stripping in a 30-year-old pine stand. The forest economy suffered losses as a result of bark stripping, which are best reflected in the calculated volumes. As in the case of other productive parameters, the tree stand volumes assumed lower values in the debarked stands in comparison with the expected volumes for a given age and valuation class. The large timber volume recorded in Tables of Stands Volume and Increment [77] for 35-year-old pines is  $287 \text{ m}^3 \cdot \text{ha}^{-1}$  with the density of  $1566 \text{ trees} \cdot \text{ha}^{-1}$ . The aggregate volume of the tree stands obtained in the first approximation (Table 3) is comparable to the one reported in the resource tables [77]. What is worth noting, however, is that the obtained volume is composed of a much higher number of trees per hectare ( $1800\text{--}3400 \text{ trees} \cdot \text{ha}^{-1}$ ). Hence, it can be concluded that the trees under analysis have lower biometric parameters, especially DBH.

The losses that forest economy can suffer through damage caused by deer also include technical shortcomings of the wood, manifestable only after logging. This is all the more important considering the fact that as many as 75% of the calculated volume can have such defects. According to a study by Welch and Scott [78], compared to biometric parameters, bark stripping may have a more significant impact on the quality of the wood, causing stain to spread around wounds and irregularities in the grain due to occlusion processes. The development of alternative methods to manage and control the deer population on this territory is necessary in light of the extensive bark stripping that was discovered in this study. Volk [30] concluded that high levels of bark-stripping occurred in mono-specific

stands and primarily in age class stands associated with poor food availability compared to multi-specific stands with different storeys. This stresses the need to consider both the density of deer, food resource availability and their interaction to reduce the intensity of bark stripping. Supplementary feeding of red deer, aimed at deflecting red deer damage, is widespread in the study area. The presented high levels of bark stripping, however, suggest that supplementary feeding did not prevent deer from stripping bark. A rational way to minimise damage in the forest economy is to perform intermediate cuts in the winter period. Leaving timber lying on the ground for a time will provide deer with coarse fibre fodder and minimise the stripping of trees intended for further cultivation.

## 5. Conclusions

The risk of extensive damage in combination with an ongoing increase and spread of red deer in Poland calls for countermeasures as well as an increased understanding of the factors affecting bark stripping from red deer. We showed that there are differences in the analysed parameters, i.e., the diameter at breast height, height, basal area and volume between damaged and undamaged trees. The high share of damaged trees (65–96%) negatively affected the biometric parameters of the pine stands. This study has reported a significant reduction in mean volume and mean basal area of the Scots pine tree stands by 41% and 39%, respectively, due to bark stripping damages caused by red deer. The number of damaged trees was also affected by the tree stand densities, where the highest percentage of damaged trees (96.3%) was identified in the plot with tree stand density of 2700 trees·ha<sup>-1</sup>. The distribution of DBH is related to the number of bark damage instances. DBH decreases along with the increase in NBDI, and the relationship is not strictly linear.

Silviculture cannot be aimed at collecting wood with the burden of defects. Reduction in the damage caused through bark stripping should, therefore, be actively strived for. The problem is often downplayed owing to a low mortality among damaged trees. However, this does not justify the negative technical consequences of bark stripping. Relevant studies should be carried out in a search for effective solutions to alleviate the pressure of cervids on forest ecosystems.

We want to focus our future studies on assessing the efficacy of measures aimed at reducing deer pressure on pine stands. The main task will be to provide deer with a balanced diet enriched with coarse fibre content, particularly during winter, while registering tree stripping instances in pine sapling stands. Such research requires commitment and coordination both on the part of foresters and hunters active in game management.

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