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Probability of Recent Bark Stripping Damage by Red Deer (*Cervus elaphus*) on Norway Spruce *(Picea abies*) in a Low Mountain Range in Germany – A Preliminary Analysis

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Red deer (*Cervus elaphus*) can cause considerable damage to forest stands by bark stripping. Here, we examined the probability of bark stripping of susceptible Norway spruce (*Picea abies*) during winter in relation to local environmental characteristics in the western Harz Mountains, Lower Saxony, Germany. We present the results of a multiple logistic regression model for recent bark stripping damage by red deer which we developed from two systematic cluster sampling inventories after two winter periods along with associated meteorological data and records of bagged deer. Our model suggests that the risk of bark stripping increased significantly ($P<0.05$) with rising slope angle, cumulating snow depth and increasing index values of red deer population density. Spruces growing in closed forest stands were debarked at a higher probability than spruces located close to forest edges. Further on, spruce stands on eastern slopes had a lower probability of bark damage than spruce stands on northern slopes.

Other tested variables (altitude, length of daily solar irradiation, duration of snow cover, age of spruce stand within the age range of 16–50 years) had no significant effect on the probability of new bark stripping. We conclude that red deer in the western Harz Mountains seem to use bark as food resource at preferred locations and in times of low food availability. To improve fit and predictive power of bark stripping models we recommend including stand characteristics. We propose to reduce the population size of red deer in order to diminish bark stripping damages to an economically acceptable level.

Keywords forest management, logistic regression, wildlife management
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1 Introduction

The presence of large intermediate feeding herbivores (Hofmann and Stewart 1972) such as 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 (Gill 1992) while at the same time having a considerable recreational and commercial value for hunting (Bützler 2001).

Whereas browsing mainly affects the growing regeneration of forest stands, bark stripping is considered as having severe impacts on actual stands. Deer peel off the bark from both deciduous and conifer trees, whereby Norway spruce (*Picea abies* L. Karst), which dominates the forest area in Germany (28.2% of total forest area) (Bundeswaldinventur 2002), seems to be preferred (Verheyden et al. 2006, Vospernik 2006).

There are ambiguous views on the effect of bark stripping on stem increment but growth losses in Norway spruce stands have been reported to range from 14–25% (Vasiliauskas 2001). However, the most important consequence of this “biological damage” (Roeder 1970) is that the unprotected wood is highly susceptible to infections with fungi which can cause stain, discoloration and timber decomposition (Vasiliauskas 2001). The percentage of stain or decay in wounds of *P. abies* ranges from 9–100% whereas in most studies, more than 50% of the wounds were infected. Closing of bark wounds in spruce is relatively slow which might also contribute to the high level of infection with pathogenic fungi (Vasiliauskas 2001). Wounds are mainly infected with the fungi species *Stereum sanguinolentum* (Alb and Schw.:Fr.) but also with *Sistostrema brinkmannii* ((Bres.) J.Erickss), *Amylostereum arolatum* ((Fr.) Boid.), *Amylostereum chaillettii* ((Fr.) Boid.), *Postia stiptica* ((Pers.:Fr) Jül.) and *Heterobasidium annosum* ((Fr.) Bref.) which invade the inner part of the stem and usually develop a typical heartrot that expands to 0.5–8.3 m, infrequently to more than 10 m, of stem length (Vasiliauskas 2001). Due to the low position of the bark damages, most of the pathogenic infections and hence most of the wood decay affects the thickest and therefore most valuable part of the stem (Vasiliauskas 2001) and the associated reduction in usable timber quantity and quality leads to a decrease of timber revenues by 20–30% (Kató 1969, Roeder 1970, Knigge 1975, Schaller 2002).

Next to the direct economic losses for the respective forest enterprises, bark stripping and associated pathogenic infections can ultimately result in death of overstory trees which – in combination with browsing of the regeneration – can alter the forest structure or even lead to local deforestation (Akashi and Nakashizuka 1999, Yokoyama et al. 2001, Ando et al. 2006).

Gill (1992) reviewed the hypothesis which might explain why deer decorticate trees. Mainly three causes are suggested to explain this particular deer behaviour: i) ranging behaviour and habitat selection of deer ii) the value of bark as food and iii) the use of bark to balance rumen pH. Recent research however corroborated the food resource hypothesis, i.e. that deer use bark as food during times of low food availability (Ueda 2002, Verheyden et al. 2006). Among other factors such as stand composition and structure, high red deer population densities have also been attributed to increased occurrences of bark-stripping (Gill 1992).

In Germany, red deer populations are restricted to distinct, mostly isolated forest regions (Bützler 2001, Becker 2002). Reliable population estimates of deer in woodland-dominated habitats are generally difficult to obtain (Smart et al. 2004) and mostly no scientific census methods are applied to estimate respective population sizes. However, hunting bags in most red deer regions in Germany are sustained on high levels and are locally even increasing (Kübler 2007). Red deer populations are known to have increased considerably both in range and population density over the last century (Gill 1990, Loison et al. 2003, Gordon et al. 2004, Ward 2005) and deer population sizes have grown faster than deer harvest numbers in Europe (Milner et al. 2006).

In light of the occurrence of considerable sized and locally increasing deer populations in forested areas there is a need for quantitative estimations of bark stripping risks to support forest and wildlife management decisions.

Therefore we aimed at identifying significant environmental factors for bark stripping which may be used by wildlife and forest managers as a decision-making aid for reducing this deer-forest conflict.

2 Material and Methods

2.1 Study Area

To obtain data for a predictive bark-stripping model, we sampled spruce stands in 55 forest districts, situated in the western part of the Harz Mountains in Germany. The study area, approximately 695 km^2 in extent, ranges from 200 to 971 m above sea level (a.s.l.) and is almost entirely (97%) covered with forest. With 68% area coverage, Norway spruce is dominating the forests. Other coniferous tree species cover 10% and broad-leaved tree species 19% of the study area (Kleinschmitt 1989). The climate of the study area is characterized by long and snowy winters, short spring periods, few sunny and many foggy days (Matschullat and Pardey 1994).

2.2 Bark Stripping Inventory

During the months of April to July 2002 and 2004 we conducted inventories to quantify new bark stripping incidences which had occurred during each previous winter period (Nov 1st to March 31st), using the protocol of Trisl (1998) which allows differentiating recent damages from old ones. The inventory followed a systematic 400 m × 400 m grid with a randomly chosen start coordinate. At each intersection, a cluster sample of three segments was taken. At the intersection itself, 20 m and 40 m north of it, the nearest tree to the given point and its five nearest neighbour trees were examined for recent bark stripping damage whereby the number of recently damaged stems but not the extent (size, position on stem, etc.) of the damages was recorded. For each cluster we calculated the share of recently debarked spruces in relation to the total number of spruce stems in the cluster sample.

We limited our bark damage inventory to spruce stands within the age range of debarking susceptibility: In and around the study area, spruces are considered susceptible to debarking between 16–50 years of age (cf. Trisl 1998, Trisl et al. 1999).

Intersections, situated on non-forested areas or on non-susceptible stands (e.g. different age classes, non spruce stands) were excluded from the inventory; single segments of the cluster sample which were located on a forest road or outside a forested area, where excluded from the sample. Number of trees per sample is therefore not uniform, either amounting to 6, 12 or 18 trees. Sampler points consisting of one or two segments were considered as located on a forest edge. The same sampler points were used for both inventory years, however due to stands growing into or out of the age-range of debarking susceptibility, number of sample plots was considerably lower in 2001/02 (n = 478 plots with 6460 trees) than in 2003/04 (n = 642 plots with 8620 trees). Due to partially missing environmental and hunting bag data, we gained complete data sets of 813 samples for our statistical analysis (382 and 431 in 2001/02 and 2003/04, respectively).

2.3 Selection and Acquisition of Explanatory Variables

Factors associated with bark stripping damages were reviewed and selected from available literature. Data on altitude (m a.s.l.), slope angle (%) and slope exposition (North, East, South, West) were derived in Arc View by cross cutting a digital elevation model with the geographic position of each sample plot. For each sample unit, we also calculated the length of solar irradiation at the 15th of each month using the same digital elevation model and mean day length of the respective month. Depth (mm) and duration (days) of snow cover were acquired from 22 climate and weather stations of the German Weather Service (DWD) in the Harz Mountains. They were allocated to the sample plots according to comparable geographic distribution, altitude, slope angle and exposition. All explanatory variables, except the index of red deer population density were compressed into classes. Since it was not possible to assess red deer density at each sampled site, we used the annual number of killed red deer per km^2 forest district area ($\bar{x} \pm SE = 12.64\ km^2 \pm 0.32\ km^2$, n = 55 forest districts) as index of local red deer population density and assigned these values to the respective sample plots.

2.4 Logistic Regression

We used a multinomial logistic regression method (block wise backward with all potentially relevant variables in order to avoid omitted-variable-errors) for data analysis. Ordinal scaled environmental variables were pre-selected using Chi-Square statistics to test the null-hypothesis of independence from the occurrence of bark stripping. The metric index of red deer population density was associated with decortication percentage by using Spearman's rank correlation (Table 1). Only variables which showed a level of $P < 0.10$ were considered for entering the logistic model.

We estimated the model parameters for the logistic regression (Eq. 1) with the maximum likelihood method, whereby the product of the probabilities that trees are classified correctly was maximised.

$$p = 1/1 + e^{-(\beta_0 + \beta_1 x_1 + \ldots \beta_i x_i)} \qquad (1)$$

where

p = probability of recent bark stripping (with p ranging from 0 to 1)
e = base of natural logarithm
β = model coefficients: β_0 = intercept, $\beta_{i>0}$ estimated coefficient for the ith explanatory variable
$x_1 – x_i$ = explanatory variables

To derive the model equations, we stepwise eliminated variables according to the probability of the Wald-test (Eq. 2) (Rudolf and Müller 2004) whereas only variables with $P < 0.05$ were kept in the final model.

$$w = \left(\frac{\beta}{s_\beta} \right)^2 \qquad (2)$$

where

w = Wald-value
β = model coefficients (s. b.)
s_β = standard error of β

For each parameter of the logistic model, we also calculated the odds ratio (Eq. 3) which can be interpreted as the change of the risk of a new bark stripping damage if an explanatory variable changes by one unit.

$$\mathrm{OR}_i = e^{\beta_i (x_{i2} - x_{i1})} \qquad (3)$$

where

OR_i = odds ratio for the ith variable
β_i = estimated coefficient of the ith variable
$x_{i2} – x_{i1}$ = change of the ith variable by one unit

Goodness of fit of the derived model was determined using the Hosmer and Lemeshow test since the model contained both dichotomous and continuous variables (Hosmer and Lemeshow 2000). Cox and Snells R^2 and Nagelkerkes R^2 (Rudolf and Müller 2004) were used to estimate the explicative power of the model. We also computed a classification table to derive the number of correctly classified trees. The model calculations were performed with SPSS 14.0.1.

3 Results

3.1 Bark Stripping Inventory

For the entire study area, the share of recently bark stripped spruces per sampling plot was similar during the two study periods, amounting to 4.77% ± 0.52% and 4.85% ± 0.48% in the winters 2001/2002 and 2003/04, respectively ($\bar{x} \pm SE$). Also, the distribution of damaged stems per sample plot was similar between both study periods, with approx. 7 tenths of the sample plots containing no damaged trees, 1 tenth of the plots with up to 10%, another tenth with 11 to 20% bark stripped trees and few sampling plots (<1 tenth) containing more than 20% trees with such damage (Fig. 1).

Slope angle, exposition, mean depth of snow cover, age of stand, location of sampler point and index of red deer population density showed a significant relationship to occurrence of recently damaged trees ($P < 0.1$, Table 1). Values of the indicated local red deer density ranged from 0.08 to 3.40 killed deer * km^{-2} in 2001/02 and from 0.00 to 3.34 in 2003/04. Hunting off take did not differ between both years ($\bar{x} \pm \mathrm{SE} = 1.21 \pm 0.11$ and 1.47 ± 0.12 in 2001/02 and 2003/04, respectively; t test, t=–1.59, DF=106, P=0.11). The variable age of stand (P<0.05 in the Wald-test) was excluded during the calculation of the final regression model.

3.2 Logistic Regression

Slope angle, snow depth, exposition, location of sampler point in relation to the edge of forest stand and index of red deer density showed significant effects on the probability of recent bark stripping damages in spruce stands during winter. The logits of being damaged by bark stripping were greater for trees on steep slopes (>50%, P=0.004) and at sites with deep snow cover (>150 mm, P=0.007) than for trees in an average environment. The risk of debarking was found to be approximately four times greater on moderately inclined slopes (21–50%) than at flat sites (slope angle ≤20%). On steep slopes it was about eight times greater. At sites covered by 61–150 mm of snow the probability of bark stripping was about six times greater and on plots covered by >150 mm of snow it was approx. eight times greater than at sites with a thinner snow mantle (≤60 mm). Spruces growing inside stands were debarked with a two times higher probability than spruces at the edges of forest stands. Exposition of spruce stands also had an effect on bark stripping susceptibility, suggesting that trees growing on eastern slopes were less likely to be debarked than spruces on northern expositions. The risk of

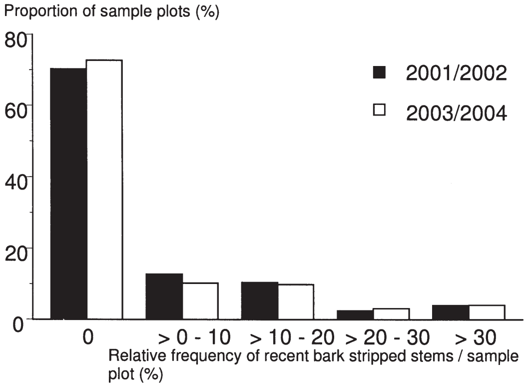

Fig. 1. Relative frequency of recently bark stripped stems per sample plot, grouped into winter periods 2001/02 and 2003/04 (100% relate to 478 and 642 sample plots in 2001/02 and 2003/04, respectively).

Table 1. Simple relationships of percentage of recent stripping of spruce bark to ordinal scaled environmental factors (using Pearson's χ^2-test) and to the metric index of red deer density (using Spearman's rank correlation (r_S) in the Harz Mountains, Germany, during the winters 2001/02 and 2003/04. [a)] No hunting bag data were available for 13 sample plots.

Environmental factor	Valid cases	χ^2-/r_S-value	DF	P
Slope angle (0–20; 21–50; >50%)	826	5.407	2	0.067
Exposition (N, E, S, W)	826	6.955	3	0.073
Altitude (200–500; 501–600; >600 m a.s.l.)	826	3.234	2	0.199
Solar irradiation (0–3; >3–6; >6–9 hrs/day)	826	2.689	2	0.261
Mean depth of snow cover (0–60; 61–150; >150 mm)	826	10.966	2	0.004
Duration of snow cover (<0.2; 0.2–0.3; >0.3–0.4; >0.4 of the number of days with snow cover per winter period, 1.0=100%)	826	5.261	3	0.154
Age of stand (16–21; 22–27; >28 years)	826	7.661	2	0.022
Location of sampler point (0=forest edge; 1=interior forest area)	824	14.362	1	<0.01
Red deer population density index (number of killed red deer * km^{-2} forest district)	813 [a)]	0.118	-	0.010

Table 2. Coefficients (B) and odds ratios (e^{β}) of significant explanatory variables ($\alpha < 0.05$) and Wald-statistics of the logistic regression model for recent bark stripping damages (reference variables: northern exposition, slope angle ≤20%, snow depth ≤60 mm, edge of forest stand).

	Coefficient B	SE (±)	Wald	DF	P	e^{β} (95% confidence limit)
Exposition			7.899	3	0.48	
East exposition	–0.568	0.275	4.279	1	0.039	0.566 (0.331–0.971)
South exposition	0.042	0.227	0.034	1	0.854	1.043 (0.668–1.627)
West exposition	–0.287	0.239	1.442	1	0.230	0.751 (0.470–1.199)
Slope angle			8.547	2	0.014	
Slope angle 21–50%	0.226	0.169	1.772	1	0.183	1.253 (0.899–1.747)
Slope angle >50%	0.909	0.317	8.547	1	0.004	2.482 (1.334–4.618)
Snow depth			8.443	2	0.015	
Snow depth 61–150 mm	0.445	0.317	1.977	1	0.160	1.561 (0.839–2.905)
Snow depth >150 mm	0.814	0.324	7.173	1	0.007	2.256 (1.197–4.254)
Red deer density index	0.270	0.101	7.173	1	0.007	1.311 (1.075–1.597)
Interior of forest stand	0.764	0.209	13.356	1	<0.001	2.147 (1.425–3.235)
Intercept	–2.451	0.406	36.523	1	<0.001	0.086

decortication increased by about 30% with each additionally killed red deer * km^{-1} forest district area (Table 2).

The validity of the model was verified with the Hosmer and Lemeshow test ($\chi^2 = 11.682$, df = 8, P = 0.166) and by the significance of the likelihood quotient ($\chi^2 = 48.788$, df = 9, P < 0.001 Omnibus test of model coefficients), thus suggesting that the model's estimates fit the data at an acceptable level.

However, goodness of fit of the model was rather meagre since both, the Cox and Snell R^2 (0.058) and Nagelkerkes R^2 (0.083) were below the desired 0.2 benchmark (Litz 2000). Overall, the logistic regression model classified 70.6% of all trees correctly, whereas 97.6% of undamaged and, owing to their relative low proportion, 5.9% of damaged spruces were projected correctly.

4 Discussion

4.1 Influence of Deer on Bark Stripping Damages

Supplementary feeding of red deer, aimed at deflecting red deer damages, is widespread in the study area. Yet, outcomes of supplementary feeding stations are extremely ambiguous with some studies showing a reduction and others an increase of deer related damages (Putman and Staines 2004 and references therein). The presented high levels of bark stripping however suggest that supplementary feeding did not prevent deer from stripping bark. Apart from its questionable effectiveness, supplementary feeding of wild deer might lead to severe changes and problems associated with deer ranging and social behaviour (Putman and Staines 2004). Therefore, we do not consider feeding as a sound management option for reducing bark stripping damages.

With yearly harvests of 1000–1400 red deer in the last decade (Rotwild Ring Harz 2006), recreational shooting is probably the main determinant of top down population control for red deer in the western Harz Mountains. However, Eurasian lynx (*Lynx lynx* L.) may kill red deer calves and yearlings but seem to prefer preying on roe deer (*Capreolus capreolus* L.) (Jedrzejewski et al. 1993) thus probably being of negligible impact for the red deer population.

Though possibly time-lagged (e.g. Fryxell et al. 1991, Solberg et al. 1999), harvest rates are likely to follow general population trends (Forchhammer et al. 1998) implying that sustained increases in hunting off take might actually be a result of increased population sizes. In the western Harz

Mountains, harvest rates of red deer did not show a clear trend in the past 10 years (Rotwild Ring Harz 2006), thus suggesting that the applied hunting practices did not reduce population size of deer.

The index of local red deer population density significantly affected debarking risk in spruces whereby each additionally harvested deer * km^{-2} increased the probability of bark stripping damage by 30%. The red deer population density has therefore a strong effect on the extent of bark stripping damage and can be seen as a key factor for controlling bark stripping damages. Thus, it is not only of ecological but also of economic interest to reduce the population density of red deer to a considerably lower level so that negative effects of deer abundance are reduced to an economically acceptable level while sustaining a vital deer population in the Harz Mountains.

Deer harvest size is influenced by policy and cultural factors such as harvesting strategies or quotas (Giles and Findlay 2004) which are, in Germany, based on detailed management plans. Trophy hunting on its own has been shown to be inadequate for regulating deer populations effectively (Fryxell et al. 1991) and reductions in population numbers can only be achieved, if hunters aim at reducing number of female deer (Milner et al. 2006). Hence we strongly recommend changing the deer management plan and current hunting practices towards harvesting – under adherence of animal welfare guidelines – considerably more adult female red deer in the western Harz Mountains.

4.2 Influence of Orographic and Climatic Factors

Among the tested orographic variables, slope angle showed a significant effect on the probability of recent bark stripping damages. Apparently, red deer preferred to decorticate trees at steep sites (>50% inclination), possibly because these stems were more easily accessible between the internodes than stems on less inclined plots. Stem branchiness may decrease stem vulnerability, in particular if internodes are short (Holloway 1968, McIntyre 1975, Ueckermann 1981). Spruces, growing at forest edges, were less likely to be debarked than their conspecifics growing in the inner part of the forest stands, possibly because these trees developed more pronounced branches (cf. Pape 1999).

Also, red deer had been shown to prefer core areas of coniferous stands during winter periods and to significantly avoid edge areas of coniferous stands (Licoppe 2006), thus suggesting that most debarking takes place in preferred habitat types. Red deer might have avoided locations close to forest roads, since they might have been disturbed by human activities (e.g. hiking, skiing) or because dense stands provide better cover. Yet, Marwede and Schneider (2004) found, that distance to roads or hunting infrastructure (e.g. raised hides) did not influence bark stripping susceptibility in the Solling Mountains, Lower Saxony, Germany. However tourist frequencies are considerably higher in the Harz Mountains than in the Solling Mountains, suggesting that the disturbance hypothesis cannot be ruled out.

Further on, access to short plants which are covered by snow may be easier on steep hillsides than on flatter terrain. On steep slopes, deer can possibly uncover the plants more efficiently by shovelling snow downhill. Snow depth greater than 150 mm significantly increased debarking risk which differed from shallower snow cover (≤60 mm, 61–150 mm). This finding underlines the food availability hypothesis (e.g. Verheyden et al. 2006), i.e. that deer use bark as a source of food in times or at locations of low food availability: Availability of food seemed to be considerably reduced by snow deeper than 150 mm and the deer seemed to feed on bark at such sites. Sika deer (*Cervus nippon* Temminck) showed a significant increase in bark stripping of hinoki cypress (*Chamaecyparis obtusa* (Sieb. et Zucc.) Endl.) in times of snow cover which did, however, not exceed 30 cm on a monthly average (Ueda et al. 2002).

Exposition of the stand also influenced the susceptibility of debarking; Red deer seemed to prefer debarking spruces growing on northern slopes and avoided damaging stands on eastern slopes. Compared to spruce stands on eastern slopes stands on northern slopes were apparently preferred by red deer as resting places, possibly because this exposition provided protection from cold eastern and predominant south-western winds.

In Austria, decortication probability was significantly related to altitude a.s.l. with greatest risks between 400 and 1200 m a.s.l. (Vospernik 2006). In the western Harz Mountains variation in altitude was considerably smaller; most plot sites were situated between 400 and 900 m a.s.l. and altitude was not significantly associated with bark stripping damage. Tree species was found to significantly affect debarking risk in Austria (Vospernik 2006) whereas we focussed on the generally preferred (Verheyden et al. 2006, Vospernik 2006), dominating tree species in our study area. Vospernik's (2006) model predicted a higher percentage of bark stripped trees correctly than ours did and had a greater pseudo-R^2-value. Partly, this may be caused by smaller sample size and more homogenous values of environmental variables and percentages of bark stripping in our study compared to the data of the Austrian National Forest Inventory (Vospernik 2006).

Even more important, Vospernik's (2006) model included variables with largely varying values such as mean tree height and breast height diameter. These stand characteristics were shown to significantly affect the probability of bark stripping damage (Vospernik 2006) but were not considered in this analysis. Despite the general positive relation between age, tree height and tree diameter, the age of spruce stand might not be an adequate substitute for these stand parameters.

4.3 Conclusion

Apparently, stand characteristics such as breast height diameter, tree height and possibly tree density and branchiness of trees are important variables explaining a considerable proportion of the variance in bark stripping susceptibility. Therefore, we strongly recommend including these variables in future bark stripping studies.

In the western Harz, long term changes in silvicultural management are on their way, aiming at establishing mixed stands of spruce and common beech (*Fagus sylvatica* L.) (Niedersächsische Landesforsten 1991). This could possibly lead to a decrease in bark stripping damages since common beech is less susceptible (Vospernik 2006). Indeed, changes in forest stands tend to process slowly, as tree species in temperate forests usually have long rotation periods and therefore we recommend implementing the outlined wildlife management recommendations to minimise current bark stripping damages.

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