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Risk factors influencing the probability of browsing by hoofed game on forest trees

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ABSTRACT: In this paper we analyze how selected risk factors determine the probability of browsing by hoofed game on forest trees. Risk factors covered by the model are: tree species (Norway spruce or Scotch pine), time period (season: spring + summer or autumn + winter) and chemical structure of bark (content of selected nutrients and chemical elements). We use a logit model for these purposes. We formulate the model and perform linear transformation by the natural log. Since the disturbance term in the logit model is heteroscedastic, we cannot use the ordinary least-squares method to estimate the parameters of the model. In this case the maximum likelihood method included in STATGRAPHICS Plus for Windows program is used for its estimation. We use a random sample of data including 59 trees. We do the interpretations of the estimated parameters and other characteristics. We demonstrate how the estimated probabilities depend on the considered factor. The model explains 44.1% of variations of the logits, the model is statistically significant. All regression coefficients are significant at least at 12% confidence level. Among the main explanatory variables (content of P, Ca, NO_3, tree species and season), the P and Ca contents in the bark of the tree are the most important factors influencing the probability of future damage to the tree.

Keywords: element contents; bark; spruce; pine; logit model; odds ratios

In order to do an effective analysis of the occurrence of damage by hoofed game on forest trees, we use the method of multivariate regression analysis and especially the logit model. We can estimate how the probability of damaged tree (browsing by fallow deer and red deer) depends on different explanatory variables such as tree species (Norway spruce or Scotch pine), time period (season: spring + summer or autumn + winter) and chemical structure of bark (amount of N, fat, ash, fibre, Ca, P, Mg, K, Na, NO_3, Co, sugar in g per kg of bark). To get good estimates of parameters of the model, it is necessary to sample a sufficient number of observations for each variable. If it is possible to quantify damage to the tree in relation to the used explanatory variables, it is convenient to use an ordinary linear model of multiple regression. First we verify the validity of regression assumptions such as homoscedasticity, independence and normality of random term and lack of multicollinearity of explanatory variables.

MATERIALS AND METHODS

The data set was collected in two hunting districts in the region of Jindřichův Hradec. The hunting district Červený jelen is situated in the Třeboň Basin between 420 and 460 m above sea level. The parent rock is predominantly sandy clay, sand, gravel and sandstone. Mean annual temperature is 7.8°C, annual precipitation is 600 mm. The main tree species is Scotch pine (representation 70%). The main hoofed game species causing damage to forest stands is fallow deer. Samples for Norway spruce were collected in the hunting district Lužánky (600–730 m a.s.l.) being a part of the upland Českomoravská vrchovina. Mean annual temperature is 6.0°C, annual precipitation is more than 700 mm. Damage to the stands of Norway spruce (representation 75%) is mainly caused by red deer. In both localities the hoofed game are present all the year round and do suffer from excessive distraction. In periods of poor food supply the hoofed game are provided food.

We collected data for the purposes of this study in the course of two years. Chemical analyses of bark of the two tree species were performed. We estimated the content of the following chemicals and chemical elements in the bark of pine and spruce: N (nitrogen), fat, sugar, ash, pulp, Ca (calcium), P (phosphorus), Mg (magnesium), K (potassium), Na (sodium), NO_3 (nitrates), Co (cobalt). All factors in the bark are measured in g per kg of bark. For each measurement we noted the season (spring, summer or autumn, winter).

The multiple logit model is a nonlinear statistical model:

$$E(Y \mid x_1, x_2, \ldots, x_k) = \frac{1}{1 + e^{-(\beta_o + \beta_1 x_1 + \beta_2 x_2 + \ldots \beta_k x_k)}}$$

Where Y is a dummy variable, i.e. $Y = 1$ with probability π and $Y = 0$ with probability $1 - \pi$ (in our conception it means that the tree is damaged or is not damaged), $x_1,\ldots,x_k$ are included explanatory variables and $\beta_0, \beta_1, \ldots, \beta_k$ are unknown regression parameters. If $k = 1$, we will get the (single) logit model. The conditional expectation $E(Y|x_1,x_2,\ldots,x_k) = 1\,\pi + 0(1 - \pi) = \pi$ can be interpreted as the conditional probability $P(Y = 1|x_1,\ldots,x_k)$. If we use n observations of all variables, the model can be formulated in a stochastic form

$$y_1 = \frac{1}{1 + e^{-(\beta_o + \beta_1 x_{1i} + \beta_2 x_{2i} + \ldots \beta_k x_{ki} + u_i)}}$$

where: u_i, $i = 1,\ldots n$ – random terms.

The estimated form of the model is

$$p_1 = \frac{1}{1 + e^{-(b_o + b_1 x_{1i} + b_2 x_{2i} + \ldots b_k x_{ki})}}$$

where: p_i – estimates of $P(Y = y_i \mid x_{1i}, x_{2i}, \ldots, x_{ki})$, $i = 1,\ldots,n$,
$b_0, b_1, \ldots, b_k$ – estimates of parameters $\beta_0, \beta_1, \ldots, \beta_k$.

The right side of this equation is a cumulative distribution function of the logistic variable. Using logarithmical transformation we get the latter model in a linear form:

$$L_i = \ln \frac{p_i}{1 - p_i} = b_0 + b_1 x_{1i} + \ldots + b_k x_{ki}$$

The left sides of those expressions L_i are called logits, and hence the name logit model. They are the log of the estimated odds ratio of damaged i^{th} tree and are linear functions of regression parameters. The odds ratio of damaged tree is the ratio of probability of damaged tree to the probability of not damaged tree (i.e. ratio $\pi/(1 - \pi)$).

The interpretation of regression coefficient b_j, $j = 1,\ldots,k$, is as follows: if variable x_j changed by a unit and the other explanatory variables remain the same, the logit L changes by b_j units. It means that the odds ratio changes $\exp(b_j)$ times. The intercept b_0 is the value of the log-odds in favour of the damaged tree if all explanatory variables remain zero.

When the logit $L = 0$, then the corresponding probability is $p = 0.5$. So we get the median value of x in a single logit model. As the value of the logit L increases, the probability p increases. The increase in the probability is not constant. The rate of change in probability p, given a change in the j^{th} explanatory variable, is

$$\frac{\partial p}{\partial x_j} = F'(b_0 + b_1 x_1 + \ldots + b_k x_k)\, b_j$$

where: F' – derivation of the cumulative distribution function of a logistic variable.

It can be shown (see Gujarati 1995) that $F'(t) = F(t)[1 - F(t)]$.

Now, the most important question arises: How do we estimate the model? If we have data on individual trees, we need the empirical values of logits but they are meaningless. In this situation we cannot use the ordinary least-squares method, however, we can use the maximum likelihood method (MLM). For the logit model the MLM is included in the package STATGRAPHICS Plus for Windows.

RESULTS

The endogenous dummy variable y equals 1 if the tree is damaged and it equals 0 if the tree is not damaged. It depends nonlinearly (according to the logit model) on the magnitude of the following exogenous variables: N (nitrates), fat, ash, pulp, Ca, P, Mg, K, Na, NO_3, Co, sugar and dummy variables representing the kind of tree (= 1 for pine and = 0 for spruce), time period (= 1 for spring + summer and = 0 for autumn + winter).

First, we can calculate the correlation matrix of all the variables. We can find that the most important exogenous variables are P, N, Mg, K, Ca, NO_3, Tree (spruce or pine) and Period (season: spring + summer or autumn + winter). The correlations between y and other variables are not significant, therefore we omit them from the model. We can also see that there is no multicollinearity in the model. Using MLM we get the multiple logit model in the form showen on the next page.

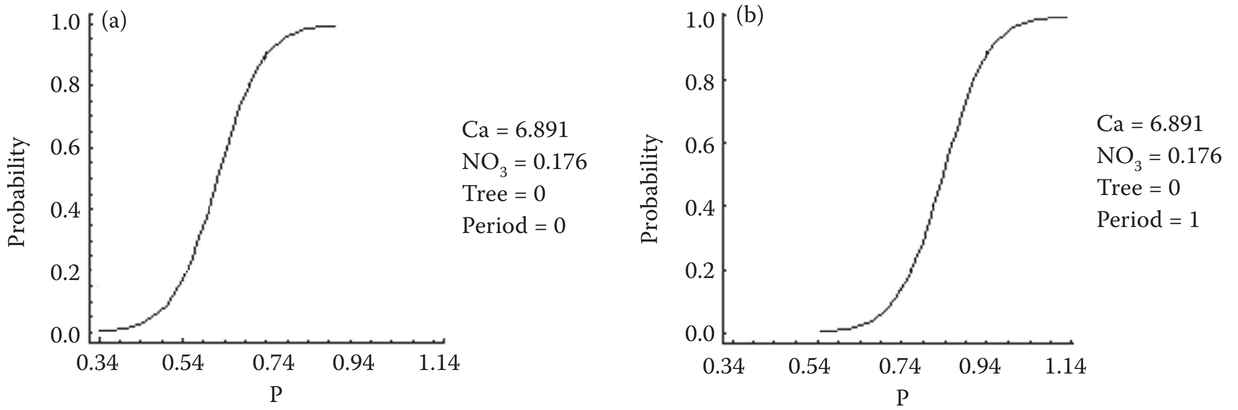

Fig. 1. Plot of the probability of damaged trees p versus the most important factor P by mean values of Ca, No_3 for spruce in the season of (a) autumn + winter, (b) spring + summer

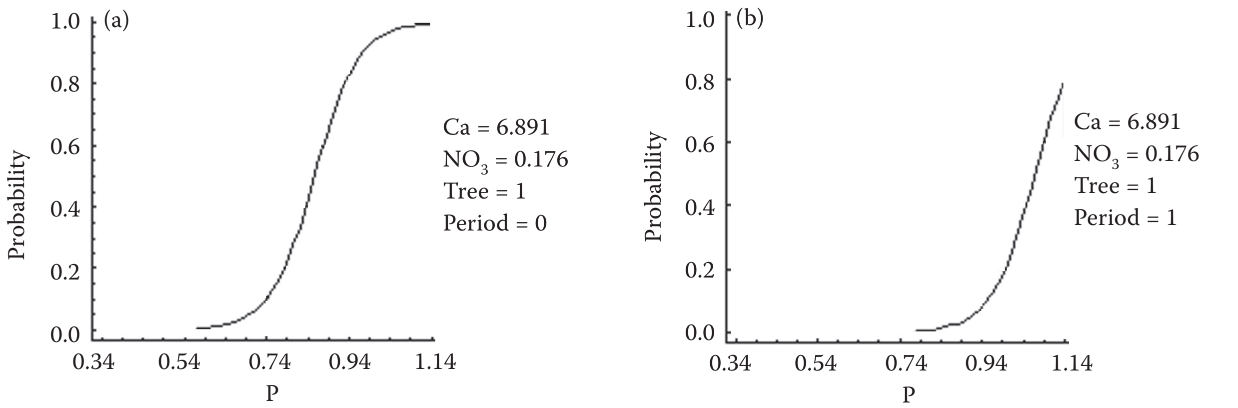

Fig. 2. Plot of the probability of damaged trees p versus the most important factor P by mean values of Ca, No_3 for pine in the season of (a) autumn + winter, (b) spring + summer

$$L = 1.701 + 26.559.P - 0.0318.N + 5.847.Mg - 1.261.K - 1.324.Ca - 46.274.NO_3 - 6.646.Tree - 4.109.Period, R^2 = 0.482$$

(p)	(0.0336)	(0.700)	(0.220)	(0.398)	(0.0186)	(0.0603)	(0.0412)	(0.0033)

where: L – logits,

p – p-values of the estimated parameters.

The variables N, Mg and K are not significant, therefore we omit them from the model. Using MLM once more we get the multiple logit model in the form:

$$L = 0.896 + 18.817.P - 1.026.Ca - 31.569.NO_3 - 4.372.Tree - 4.014.Period, R^2 = 0.441, F = 8.36$$

(s)	(5.6905)	(6.5026)	(0.5788)	(22.862)	(0.01262)	(0.01806)
(p)		(0.0001)	(0.0415)	(0.1232)	(0.0780)	(0.0019)
(o.r.)		($1.49.10^8$)	(0.358)	($1.95.10^{-14}$)	(0.0126)	(0.0161)

Now s are standard errors of estimated coefficients and o.r. are odds ratios of damaged trees.

We can see that 44.1% of L variations are explained by the model and the model is statistically significant. Using significance tests, we can find that all regression coefficients are significant at least at 12% confidence level.

We get the following interpretations of those parameters: If the amount of P increases by 1 g and the other explanatory variables remain the same, the odds ratio of damaged trees changes $1.49.10^8$ times (increases by 1.49×10^{10}%). If the amount of Ca increases by 1 g and the other explanatory variables remain the same, the odds ratio of damaged trees changes 0.358 times (decreases by 64.2%). If the amount of NO_3 increases by 1 g and the other explanatory variables remain the same, the odds ratio of damaged trees changes 1.95×10^{-14} times (decreases by 1.94×10^{-12}%). The odds ratio of damaged trees changes for pine 0.0126 times (decreases by 98.7%), for spring or summer 0.0161 times (decreases by 98.2%). We can use the estimated formula to predict the odds ratio of damaged trees by different values of explanatory variables.

Further we can calculate 80% confidence intervals for the odds ratio of all explanatory variables: (1.58×10^7; 1.39×10^9), (0.0383; 3.358), (2.08×10^{-15}; 1.82×10^{-13}), (0.00134; 0.118), (0.00193; 0.169).

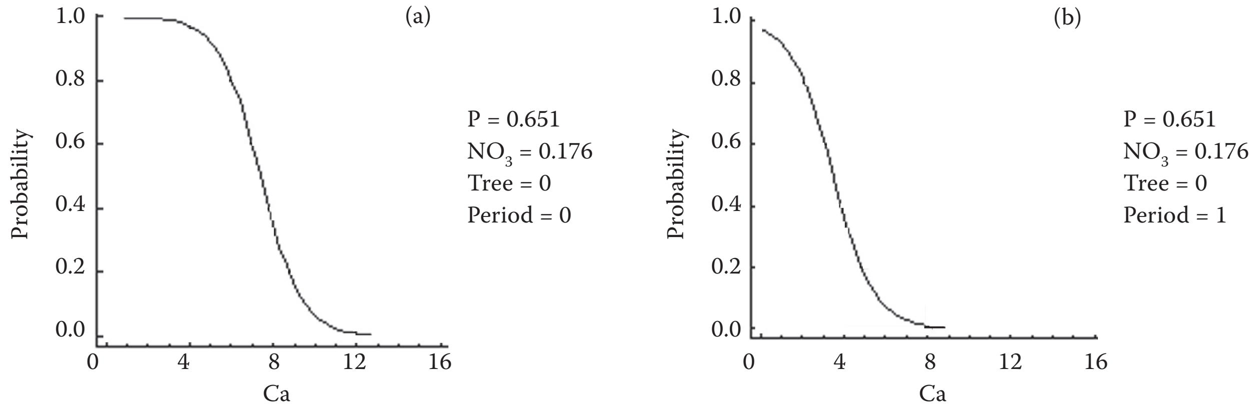

Fig. 3. Plot of the probability of damaged trees *p* versus the most important factor Ca by mean values of P, No_3 for pine in the season of (a) autumn + winter, (b) spring + summer

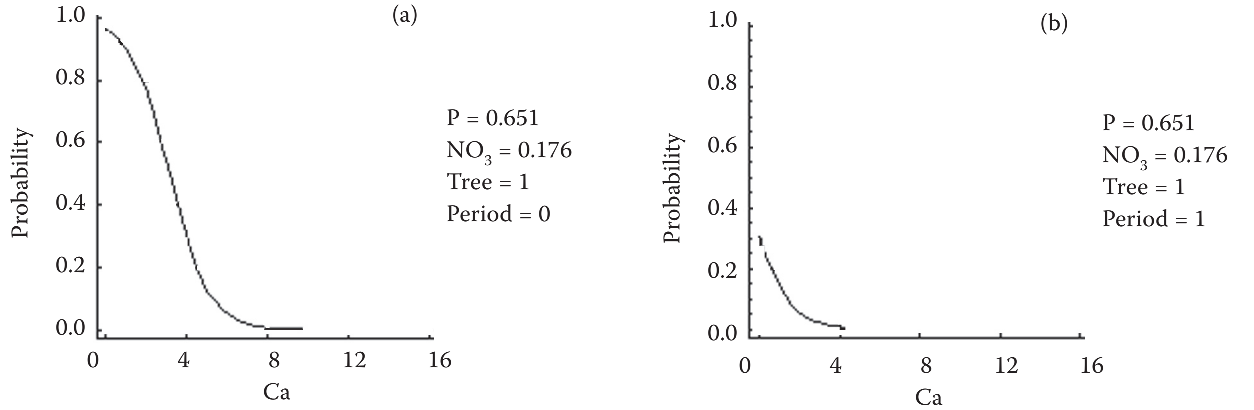

Fig. 4. Plot of the probability of damaged trees *p* versus the most important factor Ca by mean values of P, No_3 for pine in the season of (a) autumn + winter, (b) spring + summer

In order to predict the probabilities of damaged trees, we use the following nonlinear form of the estimated model

$$p = \frac{1}{1 + e^{-(0.896 + 18.817.P - 1.026.Ca - 31.569.NO_3 - 4.372.Tree - 4.014\,Period)}}$$

The probability of damaged trees *p* versus the most important factor P by the mean values of Ca (6.891 g per kg of bark), NO_3 (0.176 g per kg of bark) for spruce (Tree = 0) and autumn + winter (Period = 0) is plotted in Fig. 1a and for spring + summer (Period = 1) in Fig. 1b. The same plots for pine are shown in Figs. 2a,b.

Plots of the probability *p* of damaged trees versus the second most important factor Ca by the mean values of P (0.651 g per kg of bark), NO_3 (0.176 g per kg of bark) are shown in Figs. 3a,b and 4a,b.

DISCUSSION

We tried to explain the reasons for browsing and scaling on the level of a single tree by help of a model. It is not fully clear yet why some forest stands are heavily browsed while trees in the proximity remain untouched. For these purposes, the analyses of different factors influencing the browsing of forest trees are necessary. In our model the content of P, Ca, NO_3, tree species (spruce or pine) and time period (season) are the main explanatory variables. Among them P and Ca contents in the bark of the tree are the most important factors influencing the probability of future damage to the tree. This result corresponds with observations of Husák (1985), who stated higher P concentrations in the bark of trees damaged by red deer. Higher accuracy of the model could be achieved by increasing the number of measurements.

CONCLUSION

Browsing and bark scaling appear to be among the most important problems of forestry in the Czech Republic. The high stocks of hoofed game in combination with a decrease in the trophy of hunting districts seem to be the main reasons for an increase in damage to forest stands caused by hoofed game (Čermák, Jankovský 2006). Especially in localities with large spruce and pine monocultures, the stocks of hoofed game should correspond to the actual carrying capacity of hunting district. In such conditions bark of trees becomes a valuable source of some nutrients and chemical elements highly coveted by hoofed game. From all tree components only needles/leaves and fine roots show higher element contents than bark (Rademacher 2005). Feeding during the periods of poor food supply can positively influence the foraging behaviour of hoofed game and decrease the rate of deer browsing on forest trees. Forest managers should take into account that the availability and quality of alternative food resources vary seasonally, thus the importance of feeding may also differ between seasons.

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Rizikové faktory ovlivňující pravděpodobnost ohryzu lesních dřevin spárkatou zvěří

ABSTRAKT: V článku analyzujeme, jak vybrané rizikové faktory určují pravděpodobnost poškození lesních dřevin ohryzem spárkatou zvěří. Rizikové faktory zahrnuté v modelu jsou: dřevina (smrk ztepilý nebo borovice lesní), časová perioda (sezona: jaro + léto, podzim + zima) a chemické složení kůry (obsah vybraných živin a chemických prvků). Pro tyto účely je použit logitový model. Provedeme lineární transformaci pomocí přirozeného logaritmu. Z důvodu rozdílných rozptylů veličin pro jednotlivá měření nelze k odhadu parametrů použít obyčejnou metodu nejmenších čtverců. V tomto případě je použita metoda maximální věrohodnosti, která je součástí statistického systému STATGRAPHICS Plus for Windows. Je použit výběrový soubor 59 stromů. Následuje interpretace odhadnutých parametrů a dalších charakteristik. Je ukázáno, jak sledované faktory určují odhady pravděpodobností. Model vysvětluje 44,1 % změn poškození stromu. Všechny regresní koeficienty jsou alespoň na 12% úrovni statisticky významné. Mezi hlavními vysvětlujícími proměnnými (obsah P, Ca, NO_3, dřevina a sezona) je obsah P a Ca v kůře nejdůležitějším faktorem ovlivňujícím pravděpodobnost budoucího poškození stromu.

Klíčová slova: obsah prvků; kůra; smrk; borovice; logitový model; odhadnutá šance

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