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Interactions among the red deer (*Cervus elaphus*, L.) population, meteorological parameters and new growth of the natural regenerated forest in Snežnik, Slovenia

Marko Debeljak [a,*], Sašo Džeroski [b], Miha Adamič [c]

[a] *Biotechnical Faculty, Department of Forestry, Večna pot 83, 1000 Ljubljana, Slovenia*
[b] *Jožef Stefan Institute, Jamova 39, 1000 Ljubljana, Slovenia*
[c] *Biotechnical Faculty, Department of Forestry, Večna pot 83, 1000 Ljubljana, Slovenia*

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Abstract

Following a preliminary study (Stankovski et al., Ecol. Modelling, 108, 1998), we use machine learning techniques to conduct a more detailed analysis of the interactions among the red deer population, meteorological parameters and new forest growth. We use the machine learning program M5 (Quinlan, Proc. 10th Int. Conf. Machine Learning, Morgan Kaufmann, San Mateo CA, 1993) that learns regression trees to automate the modelling of dynamic interactions. An area of 40 000 hectares of naturally regenerated forest on the high Dinaric Karst of Notranjska, Slovenia, is studied. The analysis uses data collected during the period 1976–1993, which include several meteorological parameters, the degrees of browsing intensity of new growth of woody plants (beech and maple), and parameters about the population of red deer. Models of the degree of beech browsing and calf weight were studied earlier; here, we automatically induce models of the red deer population size, the degree of beech and maple browsing, calf weight for 1- and 2-year-olds, and hind weight. The induced models are evaluated in terms of predictive accuracy and interpreted for their explanatory power. The models show that the meteorological parameters, the parameters of the red deer population and the rates of the browsing intensity of the new growth form a complex system with closely related parameters. While these interactions can be mainly explained by our current knowledge, we still gain some new knowledge from the automatically induced models. The results emphasise the importance of a pluralistic approach and a holistic perception of the system formed by meteorological conditions, the red deer population and the new growth in a forest ecosystem.

Keywords: Artificial intelligence; Machine learning; Meteorological parameters; Models; New growth; Red deer; Slovenia

* Corresponding author. Tel.: +386-61-123-11-61 ext. 536; fax: +386-61-271-169.
E-mail address: marko.debeljak@uni-lj.si (M. Debeljak)

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1. Introduction

The diversity of indigenous animal species is an outstanding value and wildlife is among Slovenian's most important natural riches. Each individual wildlife population is a unique and unparalleled gene treasure with particular features and characteristics of an animal species and thus it must be conserved and protected in its living environment. The population of each wildlife species and its living environment constitute an integral whole and should be dealt with accordingly. Hence the conservation of wildlife is inextricably linked with the conservation of its natural environment. Guidance on the development of wildlife populations is the responsibility of all who can exert a direct influence on them or on their living environment and thus their active co-operation is a necessity. For successful work with the wildlife we have to respect the following guidelines:

- wildlife should be dealt with together with its living environment in larger ecological integral units;
- measures to be taken in wildlife populations and their living environment should be based on vegetation and wildlife population analysis, therefore regular and integral monitoring of their condition should be ensured;
- to maintain ecological balance, it is vital to ensure the implementation of planned measures in their living environment (The Forest Development Programme of Slovenia, 1996).

Slovenian hunters and foresters did not respect the mentioned guidelines for work with the wildlife in the past. This was the reason that the forest and wildlife management goals have not been harmonised and we have had big problems with natural regeneration of forests on one side and the decreasing vitality of red deer on the other side (Simonič, 1977, 1978, 1979, 1980, 1981; Veselič, 1981; Adamič and Kotar, 1983). Foresters and wildlife managers responded to these events with a new, more holistically oriented wildlife management system, which was established in 1976 (Simonič, 1982) and became known as the control method. The control method is based on the harmonisation of forest and wildlife management goals. It carefully records all implemented measures in the forest and also records the reactions of the forest ecosystem to these measures. All future measures are implemented only after a careful analysis of the reactions to already implemented measures. The application of the control method in wildlife management has given positive results. With the selective harvest of red deer and the reduction of the population size of red deer the vitality of red deer has started to increase (Simonič, 1982; Adamič and Kotar, 1983; Adamič, 1989a,b). But the improvement of the natural regeneration of trees which build the natural forest of silver fir and beech ((silver fir (*Aies alba*, Mill.), maple (*Acer psevdoplatanus* L.) and elm (*Ulmus glabra* Huds.)) was not as good as expected (Robič and Bončina, 1990; Bončina, 1996, 1997; Debeljak, 1997; Debeljak and Mlinšek 1998). This situation was not predicted, because it was expected that the harmonisation of the forest and wildlife management goals with the control method will result in increased vitality of the forest as a whole.

Ecological models can be used to represent the interactions between various elements of a given ecosystem and thus help solve environmental management problems of this kind. Artificial intelligence and in particular machine learning tools can be used to automate the process of constructing of models by using measured data on the target ecosystem to discover interactions among the ecosystem elements. Successful applications of machine learning techniques to ecological modelling problems include modelling algal growth in the Venice lagoon (Kompare and Džeroski, 1995) and the lake of Bled (Kompare et al., 1997), analysis of river water quality data (Džeroski et al., 1997) and modelling phytoplankton growth (Todorovski et al., 1997).

Regression tree induction is one of the most popular and useful approaches to machine learning from examples and has been applied to model algal growth (Kompare and Džeroski, 1995; Kompare et al., 1997). This paper is concerned with applying regression tree induction to data on a population of red deer, new forest growth and meteorological conditions with the goal of automated modelling of interactions among the mentioned factors. Preliminary experiments in this direction by Stankovski et al. (1998) indicated the potential for successful use of regression tree induction in modelling the population dynamics of red deer. This paper expands the work by Stankovski et al. (1998) by significantly widening the scope of modelling problems considered, using an improved set of data and using a machine learning method for inducing more reliable regression trees.

2. Learning regression trees with M5

Regression trees (Breiman et al., 1984) are a representation for piece-wise constant or piece-wise linear functions. They predict the value of a continuous dependent variable (called class) from the values of a set of independent variables (called attributes), which may be either continuous or discrete. Data describing a real system, represented in the form of a table, can be used to learn or automatically construct a regression tree. In the table, each row (example) has the form: $(x_1, x_2, \ldots, x_N, y)$, where x_i are values of the N attributes (e.g. meteorological parameters, estimated number of red deer in the region) and y is the value of the class (e.g., average body weight of calves of the year).

The induced (learned) regression tree has a test in each inner node that tests the value of a certain attribute, and in each leaf a rule that explains how to set the value of the class. The rule has the form of a constant value or a linear function of some attributes. Given an example for which the value of the class should be estimated, the tree is interpreted from the root. In each inner node the prescribed test is performed and according to the result of the test the corresponding left or right subtree is selected. When the selected node is a leaf then the value of the class is estimated according to the rule in the leaf.

A number of systems exist for inducing regression trees from examples, e.g., CART (Breiman et al., 1984), RETIS (Karalič, 1992), and M5 (Quinlan, 1993). Leaves in CART trees can contain only constants. RETIS can have linear functions in the leaves and also uses an m-estimate of the value of the class, which is more reliable given an appropriate value of the parameter m.

How to set m appropriately is unfortunately an open question. Also, the linear functions in the leaves always use all attributes and are thus difficult to read and interpret by domain experts. M5 is one of the most recent regression tree learning systems: it has no parameters like m in RETIS, uses only the most important attributes in linear functions in the leaves and tends to produce smaller and more reliable trees. We have therefore used M5 to model interactions among the red deer population, meteorological parameters and new forest growth.

The induced regression trees were evaluated qualitatively and quantitatively. Qualitative evaluations require the models to be inspected and interpreted by forestry and game experts. The trees shown to the experts were induced from all available data.

To quantitatively evaluate the induced trees, the average relative error of predictions and the correlation of actual and predicted values are used. For a regression tree T, the former is defined as

$$R(T) = \frac{1}{N}\sum_{i=1}^{N}\left|\frac{y_i - y(x_i)}{y_i}\right| \qquad (1)$$

where N is the number of examples, y_i is the class value of the i-th example, $x_i = (x_{i1}, x_{i2}, \ldots, x_{iA})$ are the values of the attributes of the i-th example, and $y(x_i)$ is the predicted value of the class for the i-th example by the regression tree. The method of leave-one-example-out was used, where all but one example were used to induce a tree, which is then used to predict the class value for the remaining example. In this way, we estimate the performance of the tree induced from all the available data on unseen cases.

3. The data

The data which were used in modelling the population dynamics of red deer were collected in an area of 40 000 hectares of high karst forest around mountain Snežnik in Notranjska (southwestern part of Slovenia). This area is part of the Notranjsko Wildlife Management District and part of the Postojna Forestry Enterprise. The total number of registered extractions of red deer in the Notranjsko Wildlife Management District (106 206 ha) in the period 1976–1997 (22 years) was 15 293 deer of both sexes and different age classes (Simonič, 1984, 1997). All forests in the studied area are natural regenerated and only one population of red deer lives in this area.

The experimental data are divided into four groups originating from four sources:

1. Information about the yearly harvest of red deer: year, month, age (in years), and body weight in kilograms of each harvested animal. A statistical yearbook, including the data for all extracted red deer in the Notranjsko Wildlife Management District is published every year since 1976. The data for the period from 1976 to 1993 were used in the present study.For each harvested red deer, four attributes for machine learning were created:
   - yearB-year when the animal was born
   - yearH-year when the animal was harvested,
   - age-age of extracted animal; the animals were stratified into four age classes according to their age:
     1.1. calves of the year,
     1.2. yearlings, animals in second year,
     1.3. female animals in third to tenth year,
     1.4. years and older female animals,
   - weight-weight of the harvested animal in kilograms.
2. Meteorological information: average monthly maximal diurnal air temperature, average monthly minimal diurnal temperature, monthly quantity of precipitation, number of days when the land is covered by snow per month, maximal height of the snow per month and number of days with precipitation higher than 0.1 mm per square meter per month. Meteorological information was taken from four meteorological stations and covered the period from 1976 to 1993. We had to modify the original form of the meteorological data into an appropriate form to study the influence of the winter and the summer meteorological conditions on the body weight of the red deer and on the new growth of young beech (*Fagus sylvatica* L.) and maple (*Acer pseudoplatanus* L.). We took average monthly values of the meteorological parameters and divided them into two groups:
   - average winter values of the meteorological parameters (calculated for the months: January, February, March and April),
   - average summer values of the meteorological parameters (calculated for the months: June, July, August and September). From these data nine attributes for machine learning were created:
     2.1. MaxW—average winter monthly maximal diurnal air temperature in 0.1 C,
     2.2. MinW—average winter monthly minimal diurnal air temperature in 0.1 C,
     2.3. PreW—winter monthly quantity of precipitation in 0.1 mm per m^2,
     2.4. DaySn—number of days per month when the land is covered by snow,
     2.5. DPW—number of winter days with precipitation more then 0.1 mm per m^2,
     2.6. MaxS—average summer monthly maximal diurnal air temperature in 0.1 C,
     2.7. MinS—average summer monthly minimal diurnal air temperature in 0.1 C,
     2.8. PreS—summer monthly quantity of precipitation measured in 0.1 mm per m^2,
     2.9. DayPS—number of summer days with precipitation more then 0.1 mm per m^2.
3. Information about the condition of the new growth trees: rates of browsing of beech and maple were given as the percentages of new growth trees browsed. Data about the condition of the new growth trees were obtained from materials published by the Forestry service (Udovič, 1995). From these data two attributes for machine learning were created:
   - beech—degree of browsing of beech in%,
   - maple—degree of browsing of maple in%.
4. Information about the number of red deer: given data about the red deer harvested (see a)), the number of red deer in the area was estimated using a standard method (Simonič, 1982), thus obtaining the last parameter for machine learning:

- ○ estnum—estimated number of red deer in the area for every year in the period from 1976 to 1993.

4. Results

Models in the form of regression trees were induced by M5 for six different problems: predicting the number of red deer from meteorological parameters for the current year and browsing rates, prediction of each of maple and birch browsing rates from meteorological parameters for the current year and the number of red deer, prediction of the body weight of calves of the year, the body weight of yearlings, and the body weight of hinds from age, meteorological parameters in the year of birth and the current year, the number of deer and the browsing rates.

The induced trees show the relations between the different parameters of the system.

They are presented and explained below.

4.1. Model 1: Number of the red deer

The regression tree induced by M5 for predicting the number of red deer can be transcribed as follows:

- IF the browsing rate of maple is under or equal to 46.9% THEN the

  number of red deer = 1422169 + 14.756 * rate of beech browsing (%) (2)

- IF the browsing of maple is higher than 46.9% THEN the predicted number of red deer is 2666.

The average relative error on unseen cases as measured by the leave-one-out procedure is 0.1022 or 10% (Fig. 1).

4.1.1. Wildlife expert interpretation of model 1

The top attribute in the induced tree is the degree of maple browsing, which is understandable given that red deer prefer maple (*Acer pseudoplatanus* L.) to beech (*Fagus sylvatica* L.). The model states that the size of the current deer population is proportional to the beech browsing rate if the maple browsing rate is relatively low. When the maple browsing rate is high, the number of red deer is also high.

4.2. Model 2: Degree of maple browsing

The regression tree induced by M5 consists of a single leaf with the equation

degree of maple browsing

= 19.269 + 0.011 * number of red deer (3)

The estimated average relative error of the model is 0.0996 or 10%.

4.2.1. Wildlife expert interpretation of model 2

Maple (*Acer pseudoplatanus* L.) is among the preferred browse species of red deer. It is consumed yearlong with its peak in the diet of red deer in early summer, in the period of accelerated growth of young leaves. The preference for maple and/or high degree of maple browsing were reported by several authors (Perko, 1979; Eiberle, 1985; Missbach, 1986; Adamič, 1990). Taking into account the high preference for the species, the browsing degree of maple itself might be used as a parameter of the population dynamics of ungulates in the area. According to Stankovski et al. (1998) the climatic parameters which might affect plant–herbivore interactions in the study area should be taken into account; given the small number of examples, however, no significant influence of the meteorological parameters could be proven.

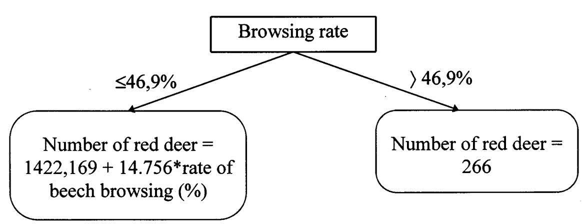

Fig. 1. Model for the number of the red deer.

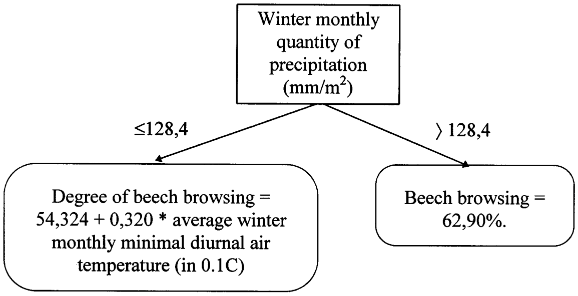

Fig. 2. Model for the degree of beech browsing.

4.3. Model 3: Degree of beech browsing

The regression tree induced by M5 for predicting the degree of beech browsing can be transcribed as follows:

- IF the winter monthly quantity of precipitation is below or equal to 128.4 mm per m^2

  THEN the degree of beech browsing

  $$= 54.324 + 0.320 \ast \text{average winter monthly minimal diurnal air temperature (in 0.1C)} \tag{4}$$

- IF the winter monthly quantity of precipitation is higher than 128.4 mm per m^2 THEN the degree of beech browsing is 62.90%.

The estimated average relative error of the model is 0.2575 or 26% (Fig. 2).

4.3.1. Wildlife expert interpretation of model 3

Beech (*Fagus sylvatica* L.) is among the moderately preferred, but yearlong consumed browse species in Wildlife reserve Snežnik (Perko, 1979; Adamič, 1990). The greatest share of total winter precipitation in the area is in the form snow. Due to different snow interception and degree of the burial of trees and shrubs in the snow, the winter food choice is affected by the snow depth in the area. The elastic and snow resistant beech is less buried and thus more exposed to the reach of red deer even in deeper snow.

4.4. Model 4: Body weight of calves of the year

Here we averaged the body weight of calves of the year and tried to predict this average value from the number of red deer, the meteorological parameters for the current year and the rates of browsing of birch and maple. The regression tree induced by M5 for predicting the average body weight of calves of the year can be transcribed as follows:

- IF the summer monthly quantity of precipitation is below or equal to 19.3 mm THEN the average body weight of the animals is 44 kg,
- IF the summer monthly quantity of precipitation is higher then 19.3 mm. THEN the average body weight of the animals is 42.94 kg.

The estimated average relative error of the model is 0.0397 or 4% (Fig. 3).

4.4.1. Wildlife expert interpretation of model 4

Red deer calves are extremely sensitive to external climatic conditions in post-birth periods. Low temperatures and extended periods with high precipitation might affect the dynamics of body growth and even cause death, due to the lack of thermoregulation in the early stages of life. Overall, high precipitation in Summer (higher than 19.3 mm) has a negative effect on the body weight of yearlings, despite positive influences of rain on the development of yearlings. The area of Wildlife reserve Snežnik is subject to submediterranean climatic impacts in summer, with extended periods of low precipitation. The rains in summer are therefore an important trigger of summer regrowth of grasses on few red deer pastures in the central part of the reserve (Adamič, 1990). Because the grasses represent the main food of milk

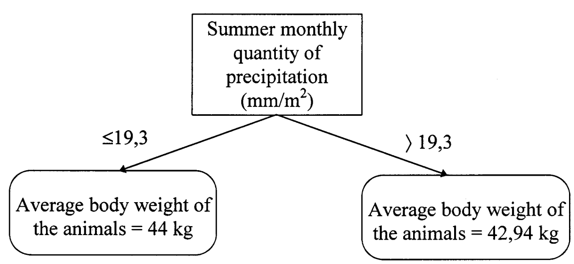

Fig. 3. Model for the body weight of calves of the year.

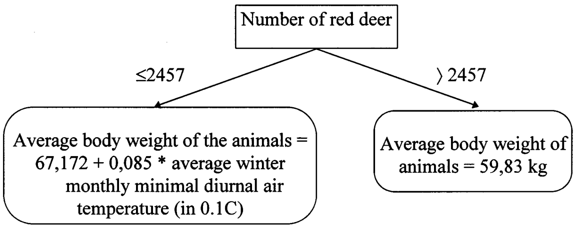

Fig. 4. Model for the body weight of red deer in the second year of life.

hinds, and therefore affect the production of the milk, suckling calves would gain more energy for the growth from the milk in rainy summers. The latter is evident also from the study on red deer on the Isle of Rhum (Clutton-Brock et al., 1982).

The impacts of winter conditions upon the body growth of calves have been reported also for Norwegian moose by Saether and Gravem (1988). Cederlund et al. (1991) discussed the influence of the severity of current winter on body weights of moose calves in Sweden. In the period November–March the calves loose more than 13% of body weight in severe winters, but gain 20% of additional weight in mild winters. The same authors stressed that snow depth was found to have more pronounced impact on the loss of body weight than low winter temperatures.

4.5. Model 5: Body weight of red deer in second year of life

The regression tree induced by M5 for predicting the average body weight of yearlings can be transcribed as follows:

- IF the number of red deer is below or equal to 2457

  THEN the average body weight of the animals $= 67.172 + 0.085 *$ average winter (5)

  monthly minimal diurnal air temperature (in 0.1 C),
- IF the number of red deer is higher than 2457 THEN average body weight of animals is 59.83 kg.

The estimated average relative error of the model is 0.0401 or 4% (Fig. 4).

4.5.1. Wildlife expert interpretation of model 5

Red deer calves and yearlings have an accelerated body growth and weight gain. Differences in food availability and food competition are therefore among crucial limiting factors of body growth in both age classes. Adamič and Kotar (1983) reported accelerated body growth of red deer calves and yearlings in the Wildlife reserve Snežnik, which was triggered by increased yearly harvest and reduction of the population density of red deer in the period 1976–1980. But even in the cases of ad libidum food availability for red deer yearlings, winter conditions (average snow depths, days with snow, minimal daily temperatures, etc.) might seriously affect their body growth and development. Clutton-Brock and Albon (1983) reported on the impacts of previous winter severity upon autumn body weights of male red deer, including the yearlings class. Saether (1985) found the fluctuations of body weights of the calves and yearlings of Norwegian moose also strongly correlated with the weather conditions of previous winter. The winter severity impacts are particularly obvious in the populations which live in poor habitat conditions.

4.6. Model 6: Body weight of hinds (female of red deer) older than 2 years

Here, we averaged the body weight of hinds of each age group for each year. The regression tree for predicting the average body weight of hinds older than 2 years can be transcribed as follows:

- IF the hind is 3-years-old

  THEN average body weight

  $= 79.347$

  $-0.41 *$ summer monthly quantity of precipitation (in 0.1 mm per m^2) in the year of birth (6)
- IF the hind is between 3 and 10-years-old

  THEN average body weight

  $= 82.113 - 0.002 *$ number of red deer

+ 0.359* age

+ 0.30 * average winter monthly maximal diurnal air temperature (in 0.1 C)

− 0.002 * winter monthly quantity of precipitation (in 0.1 mm m^2) (7)

- IF the hind is older than 10 years
  THEN average body weight

  = 87.439 − 0.004 * number of red deer (7)

The estimated average relative error of the model is 0.0454 or 5% (Fig. 5).

4.6.1. Wildlife expert interpretation of model 6

According to the model we found that the weights for hinds in third year of life (age of 2.5 years) is significantly lower if there was abundant summer precipitation in the year the hinds were born. The only reasonable explanation for that is to be sought in additional energy loss of the animals in cool and wet summers. Since this age class is still in the phase of extended body growth, any extra energy (heat) loss can reflect in reduced weight gain. Moen and Jacobsen (1975) explained the very phenomenon for white-tailed deer, with greater heat transfer surface of the bodies of younger and smaller individuals in comparison with larger ones. Parker (1988) reported for coastal black-tailed deer in summer hairs that any extended rain lasting more than 5 h at air temperatures less than 10 C elevated the energy loss above the critical levels.

The density of red deer in an area impacts the availability and individual gain of quality food sources. The latter might be of crucial importance for individual body growth and consequently for the whole population or target sex and/or age classes. Therefore, the model might be explained with intraspecific food competition for the limited food sources. This was more pronounced a good 10 years ago, at the time of birth and early growth stages of the hinds at current age of 10 years and more. Any stronger reduction of the density of red deer in the area would thus positively affects individual food availability and body growth of red deer. Adamič and Kotar (1983) have found negative correlation between the density and body weights of red deer in the Wildlife reserve Snežnik in the period 1976–1980. Brna et al. (1970) reported positive impacts of the reduction of red deer population density in the Wildlife reserve Belje in Croatia on body and antler weights of the red deer there. Positive impacts of the reduction of population density upon body growth of red deer was also found in Fichtelgebirge, Germany by Elssmann (1969).

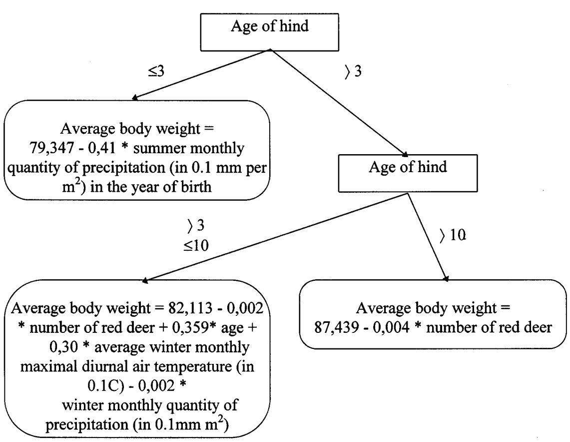

Fig. 5. Model for the body weight of hinds (female of red deer) older than 2 years.

5. Discussion

We have applied machine learning to induce models that capture the dynamic behaviour of a red deer population with regard to forest development. The models show that the meteorological parameters, the parameters of the red deer population and the rates of the browsing intensity of the new growth form a complex system with closely related parameters. While these interactions can be mainly explained by our current knowledge, we still gain some new knowledge from the automatically induced models. The results emphasise the importance of a pluralistic approach and a holistic perception of the system formed by meteorological conditions, the red deer population and the new growth in a forest ecosystem.

Our study is much more extensive than the preliminary study of Stankovski et al. (1998). The major differences are listed below.

While the degree of maple browsing and calf weight were studied in detail earlier, models for the population size, calf weight for calves of the year and yearlings separately, and hind weight were first constructed in this study.

Stankovski et al. (1998) describe models of maple browsing and calf weight, constructed using the regression tree system RETIS (Karalič 1992). Of the models described in our paper, only the maple browsing model is directly comparable to the Stankovski et al. (1998) model. Their calf model is for calves of the year and yearlings taken together; we have constructed two separate models for calves of the year and yearlings. The rationale behind this was that different factors might influence the weight of calves of the year as compared to yearlings. The differences in the constructed models provides evidence for this hypothesis.

Comparing our maple model to the model of Stankovski et al. (1998), we note that the latter, constructed from 14 examples, has seven leaves. The models in the individual leaves are supported on the average by two examples each and are thus not very reliable. The model constructed by M5 is a single equation supported by 17 examples and is thus more reliable.

Previous analyses showed that there were many errors in the data (such as having a 1 year calf weighing 100 kg). The data were cleaned up and many such errors were removed prior to the current study.

The system M5 for induction of regression trees was used, which is more robust than the RETIS system used in the previous study. The regression trees induced by M5 are smaller and more reliable, as illustrated above on the maple browsing model.

A highlight of the results of this study is the strong influence of the meteorological parameters on the ecosystem parameters, in particular on the body weight of hinds. This challenges previous simplistic approaches that presupposed simpler and more direct relationships between the red deer population and the new growth. This is a very important fact to be taken into account in the management of the ecosystem as whole.

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