Fitting Growth with the Von Bertalanffy Growth Function: A Comparison of Two Captive Maral Populations

Parés-Casanova, P.M.[1]*

Korzhikenova N.[2]

Sambetbaev A.[2]

Iglikov O.[3]

[1]*Dept. of Animal Production. University of Lleida. Catalunya (Spain)E/a: peremiquelp@prodan.udl.cat*

[2]*Dep. of Production technology of animal husbandry and fish culture products. Kazakh National Agrarian University. Almaty (Kazakhstan)*

[3]*Dep. of Biology. Semey State University named after Shakarim. Semey (Kazakhstan)*

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ABSTRACT

In this research, we used the von Bertalanffy curve for the development of a simulation model of the growth of captive marals or Caspian Red Deer (*Cervus elaphus sibiricus*). The data used in this study was from 18 male marals of Russian (n=9) and Kazakh (n=9) origin, managed under similar conditions, and measured for body weight during their growth at 9, 18 and 24 months. The curve results provided a=219.2 and c=0.163 for the "standard" Bertalanffy model, and a=194.5 and c=0.166 for the Levenberg-Marquardt model. The Akaike Information Criterion was clearly lower in the latter model (17,751) than in the "standard" one (45,652) but there were differences between the obtained and estimated weights. There were no differences in growth between Russian and Kazakh animals, and studied marals did not reach their full growth (i.e. the asymptotic level) by 2 years of age, although theoretically stags are ready to mate at 24–30 months of age. Poor feeding of stags in early life or during the antler-growing period can decrease antler production by 10–20%, so if the lack of asymptotic level indicates a deficiency in antler production, antler production is below the potential level, probably due to poor nutrition.

INTRODUCTION

The maral (*Cervus elaphus sibiricus*) is one of the easternmost subspecies of Red deer, native to areas in Kazakhstan, China, Mongolia and Russia. They are large and strong animals: adult deer can be up to 150 cm high and up to 330 kg in weight for males and 150–250 kg for females. Stem length and weight of antlers depend on the age and heredity. The amplitude of oscillation is very large. For example, at 6 years of age (they have the greatest productivity at 6–12 years of age) the average weight of antlers is 9.9 kg (2.0–11.9 kg) and the average length of the stem is 64.8 cm (45–83 cm) (Lunitsyn, 2004). Domestication of marals was initiated by Russian settlers in the Valley of Buhtarma River in the 1840s and breeding development in north-western and central Altai began in the 1870s. They are highly valued in livestock farming for the supposed healing properties of the young individuals' antlers, the so-called "Siberian deer antlers". These antlers are used to prepare a stimulating medicinal agent, called pantocrine. Siberian deer antlers are used to treat blood, cardiovascular and cranial diseases, and as a preventive against weakening of the immune system and nervous system problems. The antlers are also used as a tonic, rejuvenating drug. In these farms, special attention is given to the growth and development of marals to maturity because of the importance of antler production. The breeding evaluation depends on each animal's usage value and the development grade is obtained by measuring certain body dimensions, so one must be familiar with their growth.

Measuring the offspring's growth and development at different ages gives insight into the intensity of growth and development, which can vary as the development of certain body parts depends on genetic and ecological influences. The study of growth basically means the determination of the body size as a function of age. Information about target body weights provides farmers with an ability to compare the performance and progress of their own deer with information about the performance that would reasonably be expected as determined from various research programs. Patterns of growth for each species (or breeds) reflect the influence of season and the time to reach mature weight. Body weight, growth rate, stage of production and length of seasons are all important considerations used to estimate an animal's feed requirements that will allow it to meet production and growth targets.

Therefore, all stock assessment methods essentially work with age composition data. The simplest procedure is to determine the length of time needed to reach the desired size (for example, body weight) and to express this growth rate as kg x day-1. A growth model must take into account the way in which the growth rate of the maral slows down with increasing age and weight, which is not the case if the growth rate is expressed in kg x day-1. Red deer stags generally produce their largest antlers when they are from 5 to 7 years of age.

In classical feeding experiments, the species of growth rate is as follows: y=[lnWt–ln Wo/ætt] x 100, where W0 is the weight at time t=0 and Wt is the weight at time t. This equation is often used as it comprehensively encompasses this phenomenon. However, there are a wide range of alternative growth curves that vary in their shape, flexibility and the number of parameters that need to be fitted. Fitting a model with four or five parameters to a data set that is noisy (high error levels in the measurements) and holds a small number of points (<10) is unlikely to be successful. A less well-known growth model with two parameters is that of von Bertalanffy, in which y=a(1-be-cx). In this model, a, estimated by the maximal value of y, is the asymptotic length, and c is the growth rate parameter. Von Bertalanffy derived this equation in 1938 (von Bertalanffy, 1951) from simple physiological arguments, and it is a widely used growth curve, especially important in fisheries studies. It assumes that the animal grows towards some theoretical maximum length or weight, and the closer the length gets to the maximum, the slower the rate of size change will be. The model applied to somatic values is preferred because it is readily interpretable (Fabens, 1965), is easily comparable between studies, has well-documented derivations and applications, and can be applied to numerous advanced models.

Aiming to minimize the bias of log transformation (Smith, 1993), equation parameters were estimated by the Levenberg-Marquardt model, thus improving the fitting (Press et al., 1992). This optimization, also known as the damped least-squares, is used to solve non-linear least-squares problems. The method acts more like a gradient-descent method when the parameters are far from their optimal value.

This characteristic of the von Bertalanffy growth curve is not a constraint, as a good description of antler growth in the analytical maral growth models is more important than visualizing the "correct" physiological processes behind growth. Nevertheless, this characteristic (i.e. obtaining two parameters) makes the application of the von Bertalanffy growth curve for the mere comparison of growth cumbersome in contrast to other methods.

Within the genotype of Red deer, the pre-rut weight of males, specifically frame size, is the factor that most influences antler weights. Each 10 kg increase in pre-rut body size brings forward the date of casting by 3 to 4 days and increases antler weights by 0.12 kg. There is a general relationship between antler weight and body weight across strains of Red deer. So the purpose of this study was to study the growth curve of marals using body weight.

Previous analyses (unpublished data, 2014) have shown that, morphologically (using 10 morphological traits), adult Russian and Kazakh males (age 24 months) are different (p=0.0001). Although they do not differ for their body weight (p=0.289), are their growths similar? If yes, can they be clustered in the same growth model? As mentioned above, the von Bertalanffy growth curve has become very popular in aquaculture research, but little has been done in domestic mammals, so this is the first research of this kind for this species to the authors' knowledge.

MATERIALS AND METHODS

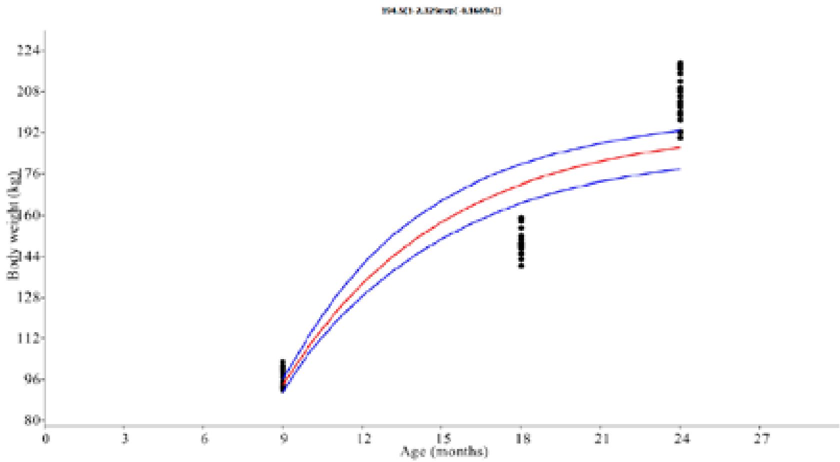
The data used in this study was from 18 male marals of Russian (n=9) and Kazakh (n=9) origin. Local marals were from the peasant farm "Bagration" (East Kazakhstan region, Ulan area, village of Privolnoye, 50° 06' N, 81° 32' E). This farm has the status of a pedigree factory for breeding Kazakh white cattle and is also a breeding farm for Simmental cattle. Maral and horse breeding are additional branches. The farm is located in a dry-steppe zone; the climate is sharp continental with large daily and annual fluctuations in temperature, spanning a range from -52.5°C in winter to +40°C in summer. The average temperature in January is -16°C and in July is +20.5°C. The average annual precipitation is between 180 and 230 mm. Average thickness of the snow cover is 30–40 cm but it can vary between 5 and 80 cm in individual winters. The soils are dark chestnut and solonetsic. Russian marals were obtained from the agricultural production cooperative breeding factory "Tenginsky" (Altai Republic, Ongudai area, village of Tenga, 50° 50' 34'' N, 85° 39' 22'' E). This farm has the status of a pedigree factory for breeding the Altai-Sayan breed of marals. The same animals were measured for body weight during their growth at 9, 18 and 24 months. Measurements were always taken by the same researcher (NK).

The "standard" von Bertalanffy model and the Levenberg-Marquardt optimization were studied. The Akaike Information Criterion (AIC) aided in the selection of the model. AIC deals with the trade-off between the goodness of fit of the model and the complexity of the model, offering a relative estimate of the information lost when a given model is used to represent the process that generates the data. Lower values for the AIC imply a better fit, adjusted for the number of parameters. The Wilcoxon signed-rank test, a non-parametric statistical hypothesis test, was the used to compare matched samples (real and estimated body weight) to assess whether their population mean ranks differed. Finally, an ANCOVA (Analysis of Covariance) was used to compare models between Russian and Kazakh animals. Statistical treatments were done with PAST v. 2.17c (Hammer et al., 2001).

RESULTS AND DISCUSSION

The results provide a=219.22 and c=0.163 for the "standard" Bertalanffy model, and a=194.47 and c=0.166 for the Levenberg-Marquardt model. AIC was lower in the

Figure 1. *Body weight according to age of marals according to the Bertalanffy model, with Levenberg-Marquardt optimization (which showed a lower Akaike Information Criterion than the "standard" model). The results provide a=194.4 and c=0.166. The best fitting growth function is indicated by the solid central line, and the external lines indicate the 95% confidence zone. The Wilcoxon test showed statistical differences between the obtained (filled dots) and estimated weights (W=1275, p<<0.0001).*



Levenberg-Marquardt model (17,751) than in the "standard" one (45,652), which is shown in Figure 1. The Wilcoxon test showed statistical differences between the obtained and estimated weights (W=1275, p<<0.0001) but – as the model is intended more as an analysis of growth (results are easily interpreted as "growth rates) than a predictive model – it is acceptable. Moreover, ages are not known exactly for each individual, so only three "estimated body weights" were obtained. Although value a for the Levenberg-Marquardt model –which can be interpreted as the mean body weight the animals reach if they were to grow indefinitely (that is, 187.7–204.4 kg) – is well below the average body weight for 24-month-old animals (205.2±9.05 kg), the curve does not reach an asymptotic level. The high range of weight for this age (140.4–219.0 kg, CV=16.36%) could explain why the real body weights are higher than the fitted weights (Figure 2). ANCOVA showed no differences in growth between Russian and Kazakh animals (F=0.601, p=0.441; Figure 3).

The von Bertalanffy growth curve implies that the growth rate declines linearly with length. Theoretically, stags are ready to mate at 24–30 months of age, but the studied marals appear to not reach their full growth (i.e. the asymptotic level) by 2 years of age. If the lack of an asymptotic level in the curve indicates a deficiency in body weight (possibly due to poor feeding), antler production will be below its potential level (poor feeding of stags in early life or during the antler-growing period can decrease antler production by 10–20%). In conclusion, maral managers should ensure that the animals' genetic potential for antler size is not compromised by poor nutrition as appears to occur at present.

Maral growth parameters, of course, can differ from breed to breed and also from stock to stock, which is why further studies with more animals from other stocks and including more age groups would be desirable. When collecting samples for an age/body-weight key, it would also be important to include in the sample some very young, and some very old specimens, with exact

Figure 2. *Box plot of body weight for groups aged 9, 18 and 24 months. For each group, the 25–75 percentage quartiles are drawn using a box. The median is shown with a horizontal line inside the box. The minimal and maximal values are shown with short horizontal lines ("whiskers"). The whiskers have been drawn from the top of the box up to the largest data point less than 1.5 times the box height from the box (the "upper inner fence"), and similarly below the box.*

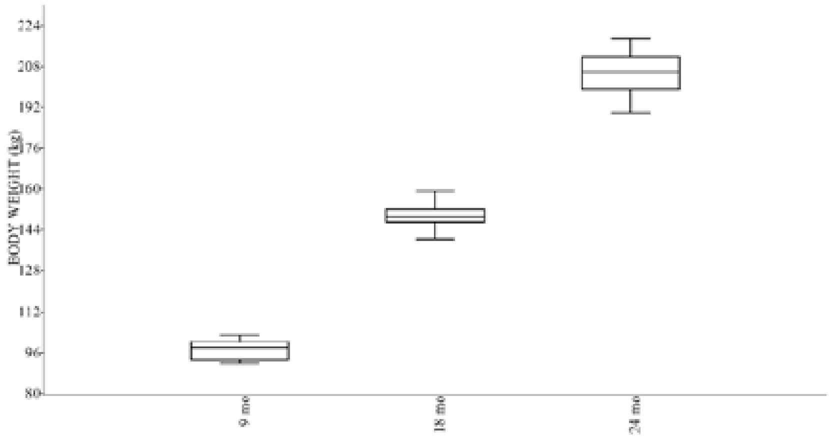
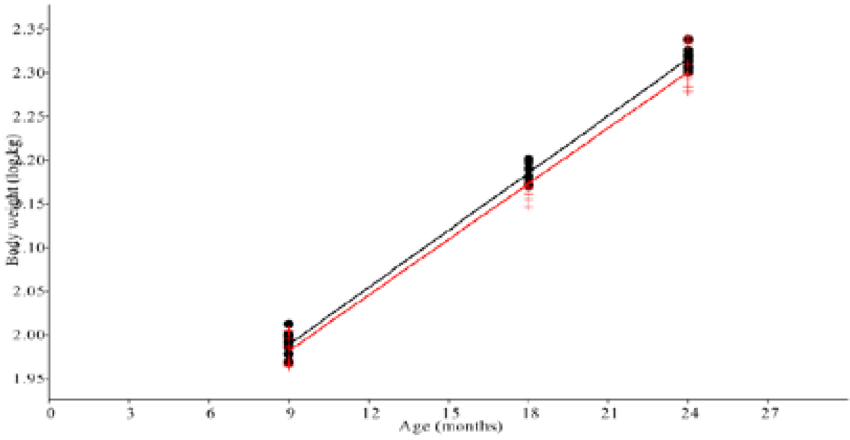


Figure 3. *ANCOVA (Analysis of Covariance) for growth in groups from each origin. This analysis showed no differences in growth between Russian (crosses, n=9) and Kazakh (filled dots, n=9) animals (F=0.601, p=0.441).*



age known. When improving management conditions, managers must also consider the genetic influence of dams on antler production because they contribute 50% of the genes for antler production.

REFERENCES

1. Hammer, Ø., Harper, D.A.T., Ryan, P.D. 2001. PAST: Paleontological Statistics Software Package for Education and Data Analysis. *Palaeontologia Electronica* 4 (1). On line http://palaeo-electronica.org/2001_1/past/issue1_01.html.
2. Lunitsyn, V.G. 2004. Antler deer breeding of Russia. *Russian Academy of Agricultural Sciences. Siberian branch of the Russian Research Institute of antler deer breeding. Barnaul*: 151-159.
3. Press, W.H., S.A. Teukolsky, W.T. Vetterling & B.P. Flannery. 1992. *Numerical Recipes* in C. Cambridge University Press.
4. Smith, R. J. 1993. Logarithmic transformation bias in allometry. *American Journal Physical Anthropology* 90: 215-228.
5. von Bertalanffy L. 1951. *Theoretische Biologie*, Zweiter Band: Stoffwechsel, Wachstum. A Francke AG Verlag, Bern, Switzerland, 418pp.