HORN GROWTH DOES NOT CONTINUE AFTER FULL BODY GROWTH IN CATALAN GOAT BREED

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Summary. In animals, horn length as an exaggerated sexually selected trait should impair functional capabilities and impose fitness costs. Then, it would be logical that a limit to horn growth exists, even in domestic ungulates. Our objectives were (1) to find out the limit of horn growth in Catalan goat (2) to investigate whether this growth could be adjusted to a mathematical model; in other words, if there was a non-linear model that could parametrise horn growth. The current study included data (body weight and horn length) from 66 animals (6 males, 53 females and 7 wethers) belonging to the 'Catalan goat' population. Four non-linear models (logistic, von Bertalanffy, Michaelis-Menten and Gompertz) were compared based on the degree of fit and estimation of the growth patterns of horns according to body weight. The logistic model $y= a/(1+be–cx)$ best fitted the data. In this model, horn growth starts in a low acceleration phase, which has a slight inflection, making horn growth slow until the animal reaches its complete body weight (57±6.5 kg), when this rate keeps reducing, approaching zero. The asymptotic growth level indicates that horn growth does not continue after full growth. Early individual development would seem not to affect definitive horn length, because of apparent compensatory growth. This has substantial implications for management and conservation of the breed, because of the potential current impact on selection of adults by only taking into account horn length.

Keywords: allometry, Caprinae, Catalan goat, morphometry, skull.

Introduction. In domestic ungulates, much attention has been paid to the role of horns. Horns are thought to be costly because they require energy and nutrients to grow, they represent a heat loss during winter (Picard *et al*., 1996), and carry costs are high (Geist, 1966), so life history theory assume that large horns should have more fitness cost. On the other hand, there could exist a positive relationship between horn growth and longevity (Reznick *et al*., 2000), because weaker individuals may have small horns and die younger (Cam *et al*., 2002). However, at the same time, horn length as an exaggerated sexually selected trait should impair functional capabilities and impose fitness costs. Then, it would be logical that a limit to horn growth exists, even in domestic ungulates. However, in domestic ungulates one could see an added problem when studying horns, which is that their evolution is not driven only by sexual selection, but also (sometimes mainly) by artificial selection. The conspicuous horns of White Rasquera goats (a domestic breed from North East Spain) exemplify the extreme horn morphologies (both in length and in form) that can result from artificial selection, the traits that stockbreeders assess the most when they choose males as future bucks (*pers. obs*.).

Yet, curiously, little research has been conducted on domestic goat horn growth. One objective of this study was to find out the limit of horn growth in Catalan goat. Another was to investigate whether this growth could be adjusted to a mathematical model; in other words, if there was a non-linear model that could parametrise horn growth. Logistic, von Bertalanffy, Michaelis-Menten, and Gompertz models are part of the non-linear model 'family' and they were chosen because they have been used for a long time to describe growth of organisms (Thornley and France, 2007).

The ancient population of Catalan goat occupied Catalonia (NE Spain) until the middle of the 20th century, and was well adapted to harsh interior Mediterranean hills in the Catalan Pre-Pyrenees region. Remaining animals are medium-sized, have a slender neck and sloping rump, are relatively long-legged and short-haired, with characteristic long hair on the upper thigh, and have a haired udder. Both sexes have horns, typically bending sharply backwards ('aegagrus' type), although some have corkscrew-shaped horns that curve back and outwards ('prisca' type). The breed is clearly different from other neighbouring Catalan breeds, e.g., Pyrenean and White Rasquera (*pers. obs*.).

Materials and Methods

Ethics considerations

No specific permits were required for this study, as it involved neither slaughtering of any animal nor manipulation of endangered or protected specimens.

Study population

Sixty-six animals belonging to the Catalan goat population were studied in the 'conservation farm'. Six animals were males, 53 females and 7 wethers. As Kruskal-Wallis test showed no differences in horn length between them (Hc=1.835, p=0.399), sexes were pooled. Body weight was measured using a hanging digital scale and measured to the nearest 0.1 kg. Right horn length was measured with a tape along the whole length of its sheath. Pregnant females were avoided in sampling.

Growth models

There are several types of non-linear models, among which we considered the logistic, von Bertalanffy, Michaelis-Menten, and Gompertz ones. The logistic equation is $y= a/(1+be^{–cx})$, where x represents time and a,b,c are positive parameters. The value of a is first estimated by the maximal value of y. The values of b and c were then estimated using a straight-line fit to a linearised model. The von Bertalanffy option uses the same algorithm as above, but fits to the equation $y= a(1–be^{-cx})$. The Michaelis-Menten option fits to the equation $y= ax/(b+x)$. This algorithm uses maximum likelihood estimators for the so-called Eadie-Hofstee transformation (Raaijmakers, 1987; Colwell and Coddington, 1994). The Gompertz option fits to the equation $y= a$*exp(b*exp(cx)).

Table 1. **Results for the four models studied. Of the different non-linear regression equations compared, the logistic one showed the best depiction for horn growth according to body weight (e.g. the lowest AIC)**

Model	.*a*	.*b*	.*c*	AIC
Logistic	52.55	14.87	0.07	1740.5
Von Bertalanffy	52.55	2.34	0.04	2622.9
Michaelis-Menten	-408.59	-642.58	--	1777.1
Gompertz	52.55	-5.34	-0.05	1900.0
AIC: Akaike Information Criterion				

Table 2. **Confidence Intervals (95%) of the parameters *a*, *b*, and *c* for the logistic model**

Model	.*a*	.*b*	.*c*
Logistic	52.55	-4.92	0.044
	59.06	20.24	0.080

Based on the obtained parameters, a growth curve was plotted for both sexes using the logistic model (Figure 1).

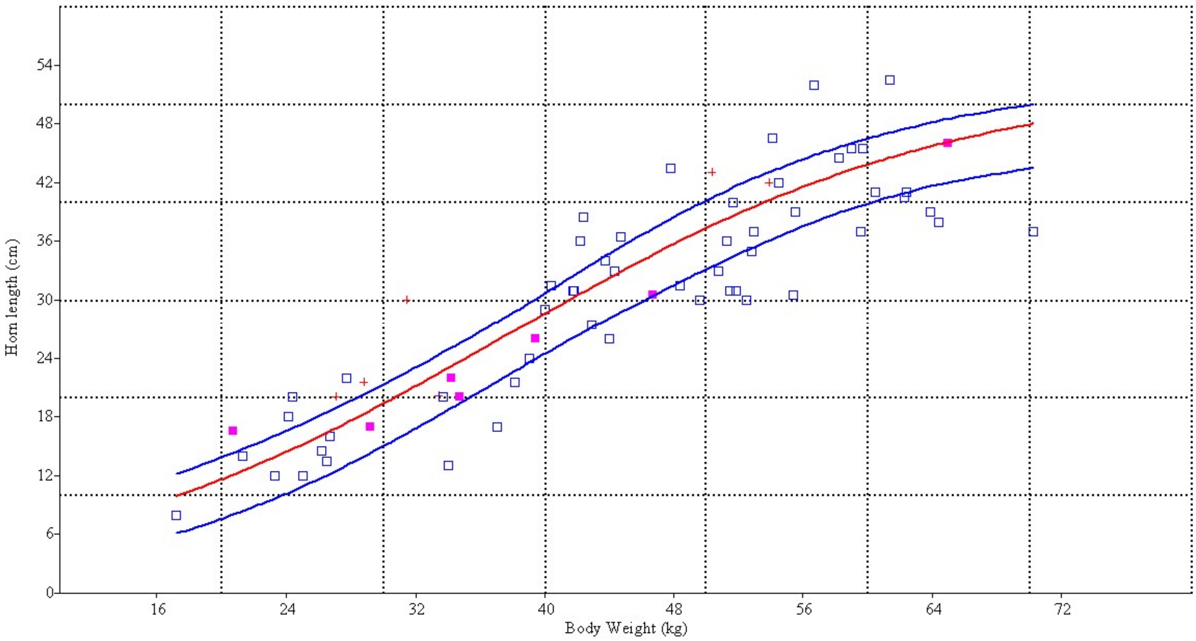

Figure 1. **Plot of the logistic model (n=66) (6 males –crosses-, 53 females –empty squares- and 7 wethers –filled squares-). The model presents values homogeneously distributed along the line during all growth stages. The asymptotic level indicates that horn growth does not continue after full growth.**

When animal growth is studied, these models should be fitted to the situation in which they will be applied. In non-linear regression models, the asymptote value (a) corresponds to the estimated inflection point of the growth curve, i.e., when horn length no longer changes with time. Thus, it indicates mature horn length or maximal theoretical weight. The scale parameter (b) does not have a biological interpretation, and it is established by the initial y and t values after birth. Maturity index (c) estimates the relative rate in which the asymptotic value is reached. This parameter is a logarithm function of weight, changing linearly per unit of time. Thus, it can be interpreted as the slope of the curve. The initial estimate was computed using regression on a linearised model. The Akaike Information Criterion (AIC) was used in the selection of model. Lower values for the AIC imply a better fit, adjusted for the number of parameters. Based on the obtained parameters, growth curves were estimated for both sexes. Prediction error was calculated as a percentage of deviation of observed length from estimated

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length divided by the observed length. Data were analysed using PAST (PAleontological Statistics SofTware Package for Education and Data Analysis) (Hammer *et al.*, 2001).

Results. Parameter estimates of horn growth curve models for males, females, and both sexes are shown in Table 1. For adult males, the coefficient of variation of horn length (36.1%) was similar to that of body weight (30.3%). The logistic model presented the lowest AIC. It presented values homogeneously distributed along the line during all growth stages. Equal estimates of parameter *a* (asymptotic length) were obtained using the logistic, von Bertalanffy, and Gompertz models. The highest estimation of parameter *c* was obtained in the logistic model. Low standard errors indicated a good estimation of this parameter (Table 2).

Discussion. The primary function of a mathematical model is to provide the best depiction of the phenomenon one wants to describe. Of the different non-linear regression equations compared, the logistic one showed the best depiction for horn growth according to body weight. This model has been applied widely in social sciences, econometrics, genetics, and biomedical studies (e.g., Qureshi *et al*., 2000; Montgomery, 2002; Scarpa *et al*., 2003a, b; Zhou *et al*., 2004). The adequacy observed is evidently associated with the basic premise of the non-linear models: a growth rate that admits, at most, one inflection point over growth. In the logistic model, horn growth starts in a low acceleration phase (increasing rate), which has a slight inflection, making the horn growth decelerated (decreasing rate) until the animal reaches a weight close to the weight at maturity (57±6.5 kg), when this rate keeps reducing, approaching zero. The asymptotic level indicates that horn growth does not continue after full growth. Early development seems not to affect adult mass, because of apparent compensatory growth.

This conclusion has substantial implications for management and conservation of the breed, because of the potential current impact of selection of adults by only taking into account horn length. Now, behavioural data would be required to provide a better understanding of the relationships between horn size, reproductive effort and longevity, all of which could affect the age-dependent tradeoff between horn size and reproductive success.

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