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GROWTH CURVE AND WEIGHT ESTIMATES OF PHILIPPINE SWAMP BUFFALO (*Bubalus bubalis* LINN.) IN CAGAYAN

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ABSTRACT

The study was conducted to determine the weight and height of Philippine swamp buffalo (PC) in Philippine Carabao Center at Cagayan State University from birth (0 month) to 60 months of age with 3-month interval and establish a growth curve model that best fit the breed. Data of weight from the year 2001 to 2017 and height from 2001 to 2015 were analyzed. The data of PC were used to determine growth curve using four nonlinear models (Logistic, Gompertz, Von Bertalanffy and Brody). Three parameters used in the model were mature weight and height (W_∞ and H_∞), birth weight and height (W_0 and H_0), and maturing index (*k*). The Brody model had the lowest Akaike Information Criterion (AIC) and had a high degree of accuracy in predicting weight and height regardless of sex. The Brody growth curve model best fit the data set of weight and height for all, male and female PC. Multiple linear regression of body weight on three body measurement parameters (Age-Cat, HG and BL) was performed. The model BW = -131.377244 + 2.818707(Age-Cat) + 1.095026(BL) + 1.150713(HG) had an R^2 of 0.94.

Key words: growth curve, Nonlinear Growth Curve Model, Philippine swamp buffalo

INTRODUCTION

The Philippine native carabao (PC) is a swamp type of buffalo and is best known as the "beast of burden" by farmers in the Philippines. It is a major contributor to the total agricultural economy of the country (DOST-PCARRD, 2002). The Philippine Carabao Center at Cagayan State University and DA-PCC, established a breeding program for the PC which aims to increase the growth rate and meat production potential of the animals in the institutional herd. Body weights, average daily gain (ADG) and body conformation of the same age group are the traits selected to determine superior individuals for breeding. Using data from this center, body weights at 12 and 18 months of age had the largest improvement, as bulls were selected at these ages (Flores, 2017). However, it is important to determine the inflection point of growth to have more accurate estimates of genetic parameters for weights.

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Growth reflects the lifetime interrelationship between an individual's inherent impulse to grow and mature all body parts and the environment (Santos *et al*., 1999). Nonlinear models are used to derive growth curves in livestock, fishery, and crops (Zwietering *et al*., 1990). Specifically, in livestock and poultry, growth curves of cattle (Goncalves *et al*., 2010), riverine buffaloes (Malhado *et al*., 2017), lambs (Sieklicki *et al*., 2017), sheep (Behzadi *et al*., 2014), quail (Drumond *et al*., 2013) and chicken (Yakupoglu and Atil, 2001) were derived using nonlinear models. The present study determined the growth curve for weight and height in male and female PC. Further, prediction equation for weight with age, wither height, body length and heart girth as predictor variables was done and validated.

MATERIALS AND METHODS

There were 5,714 and 3,295 available records of body weights (from 2001 to 2017) and wither heights (from 2001 to 2015), respectively, from 272 animals that were used and analyzed for PC growth curve. Both sexes of the animals were considered in the overall analysis and separate analysis were conducted for male and female. Body weight (WT) and wither height (HT) were recorded every month using a digital animal weighing scale (TrueTest 2000®) and meter stick, respectively. Average weight, wither height, body length and heart girth were taken for each age groups from 0 (at birth) to 60 months with 3-month interval (i.e. 0, 3, 6, 9, 12, etc.).

Four nonlinear models (Logistic, Gompertz, Von Bertalanffy and Brody) were used to describe the best fit growth curve of PC, similar to the previous report (Teleken *et al*., 2007). The output from JMP v8 software includes Akaike Information Criterion (AIC) and RMSE, which are determinants in choosing the model that best fits the data set. The lower the value of corrected Akaike Information Criterion (AICc) the better estimate (Gbangboche *et al*., 2008; Teleken *et al*., 2017). There were 21 experimental points (0, 3, 6, 9, 12, 15, 18, 21, 24, 27, 30, 33, 36, 39, 42, 45, 48, 51, 54, 57 and 60 months) for height and weight per animal. Three parameters for weight and height were used to define and predict the shape of the growth curve in the model; W_∞ and H_∞ estimate the mature weight and height, W_o and H_o for birth weight and height and *k* refer to weight and height maturity index. Since the number parameters of the model (*K*) is less than 40, the corrected AICc formula was used in the present study to increase the level of accuracy. It is defined as AICc=AIC+(2K(K+1)/N-K-1) (Burnhum and Anderson, 2002).

For predicting body weight using morphometric measurements, there were 254 animals with 352 records of heart girth (HG) and body length (BL) from the year 2016 to 2017. Records were analyzed using correlation and linear regression functions of JMP v8 software. Body weight was correlated with age category (Age-Cat), HG and BL. Prediction of body weight was done using the regression model: $y = \alpha + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \epsilon$, where: y = mean response dependent variable, α = intercept or the mean response, β = coefficient or the change in the mean response, x = regressor or the independent variable and ϵ = error or residual. Data validation was also done.

RESULTS AND DISCUSSION

The average body weights of PC from birth up to 60 months old for all animals and between male and female are presented in Table 1. Significant increase in body weight (P<0.05) of PC was observed from birth until 60 months for all animals but not in all ages. No significant differences (P>0.05) in body weight of PC were noted between ages 30 and 33 months, 36 and 39 months, 42 and 45 months, 45 and 48 months, 48 to 54 months, 54 and 57 months, and 57 and 60 months. This suggests that weighing of the animals for monitoring purpose can be done on a 6-month interval starting at 30 months old onwards.

The PC is physiologically mature at 24 months, although recommended body weight of 300 kg for breeding is only attained at 30 months old in male and 33 months old in female. Significantly higher weights (P<0.05) were noted in female PC than male PC at ages 6, 12 and 15 months and the reverse were found in ages 36, 39, 51, 57 and 60 months

Table 1. Average weight (WT±SE, kg) of PC at different age and sex.

Age (Months)	N	All [abc] WT±SE	N	Male WT±SE	N	Female WT±SE
0 (At birth)	260	29.5±0.2[a]	133	29.8±0.3[ns]	127	29.3±0.3[ns]
3	467	62.6±0.9[b]	243	61.2±1.2[ns]	224	64.2±1.4[ns]
6	668	99.5±1.1[c]	348	97.1±1.5*	320	102.0±1.6*
9	636	132.7±1.4[d]	329	130.4±1.9[ns]	307	135.2±2.0[ns]
12	609	160.1±1.6[e]	305	156.1±2.2*	304	164.1±2.4*
15	334	182.1±2.3[f]	171	177.1±3.0*	163	187.3±3.5*
18	304	199.3±2.4[g]	154	195.7±3.2[ns]	150	203.0±3.5[ns]
21	285	221.4±2.7[h]	130	218.6±4.1[ns]	155	223.7±3.5[ns]
24	251	244.9±3.0[i]	98	246.8±4.8[ns]	153	243.7±3.8[ns]
27	273	267.1±2.9[j]	109	262.2±4.9[ns]	164	270.4±3.5[ns]
30	196	295.9±3.0[kl]	74	301.9±4.6[ns]	122	292.3±4.1[ns]
33	209	310.1±3.1[l]	70	315.3±5.4[ns]	139	307.5±3.8[ns]
36	143	337.8±3.6[m]	41	352.1±6.0*	102	332.0±4.4*
39	184	346.6±3.6[m]	44	359.8±7.7*	140	342.5±4.0*
42	134	367.1±4.1[n]	25	378.6±8.7[ns]	109	364.5±4.7[ns]
45	117	382.1±4.2[no]	13	397.1±13.2[ns]	104	380.2±4.5[ns]
48	113	397.5±4.5[op]	16	412.7±11.0[ns]	97	395.0±4.9[ns]
51	156	402.3±4.1[p]	27	429.9±12.8*	129	396.6±4.1*
54	133	409.1±4.1[pq]	17	41.9±10.3[ns]	116	404.3±4.3[ns]
57	128	418.6±4.3[qr]	19	474.3±8.8*	109	408.8±4.2*
60	114	429.1±4.9[r]	16	502.7±7.5*	98	417.0±4.6*

[abc]Means in column followed by different letters are significantly different at P<0.05, mean separation by HSD.
*significantly different at P<0.05
[ns]not significant

old. The rest of the ages did not vary (*P*>0.05) from one another. Selection of animals for either fattening or breeding purposes can be started at 18 to 24 months old with 200 to 250 kg weights. Any animal that has weights higher for their age are fast growers and can be selected for breeding.

The average height of PC at different age and sex category is presented in Table 2. Height of PC increased significantly (*P*<0.05) as the animal grows from 0 (at birth) until 12 months old. No significant differences (*P*>0.05) in height were observed in age 15 and 18 months, 18 and 21 months, 21 and 24 months, 24 to 30 months, 30 to 36 months, and 36 to 60 months. Also, there is no significant difference (*P*>0.05) in height between male and female from birth to 60 months of age. This indicates that male and female PC grow in height at the same level with age.

The goodness of fit obtained from growth curve models applied to the average weight and height of PC is summarized in Table 3. The Brody model showed the best model

Table 2. Average height (HT±SE, cm) of PC at different age and sex category.

Age (Months)	**N**	**All [abc] WT±SE**	**N**	**Male WT±SE**	**N**	**Female WT±SE**
0 (At birth)	220	67.8±0.4[a]	113	68.2±0.5	107	67.3±0.6
3	388	78.8±0.4[b]	188	79.3±0.5	200	78.3±0.5
6	571	89.5±0.3[c]	284	89.4±0.4	287	89.7±0.4
9	545	96.0±0.3[d]	268	96.0±0.4	288	96.0±0.4
12	519	100.8±0.3[e]	248	101.0±0.4	271	100.7±0.4
15	184	103.6±0.4[f]	82	103.6±0.7	102	103.6±0.6
18	168	105.7±0.4[fg]	76	109.3±0.7	91	105.6±0.6
21	148	107.5±0.5[gh]	54	111.2±0.8	94	107.4±0.6
24	132	109.2±0.5[hi]	45	114.8±2.6	87	109.2±0.6
27	103	111.4±0.5[i]	39	116.2±1.0	64	111.6±0.7
30	19	112.8±1.5[ij]	4	114.8±2.6	15	112.3±1.8
33	80	115.0±0.6[j]	29	116.2±1.0	51	114.3±0.8
36	23	116.3±0.9[jk]	8	116.8±1.8	15	116.1±1.0
39	67	116.7±0.5[k]	22	117.7±1.1	45	116.2±0.6
42	7	118.6±0.6[k]	1	118.0±0.0	6	118.7±0.8
45	12	118.8±0.9[k]	1	117.0±0.0	11	118.9±0.9
48	22	120.0±0.9[k]	1	127.0±0.0	21	119.6±0.9
51	45	118.8±0.6[k]	11	119.7±1.0	34	118.6±0.7
54	4	118.3±1.8[k]		NDA	4	118.3±1.8
57	17	118.7±1.1[k]	57	122.5±2.5	15	118.2±1.2
60	21	119.0±0.9[k]	60	120.8±0.8	17	118.5±1.1

[abc]Means in column followed by dissimilar letters are significantly different at *P*<0.05, mean separation by HSD.
NDA= no data available.

Table 3. Test of goodness of fit obtained from growth models applied to the average weight (kg) and height (cm) of PC.

Mathematical Model	All			Male			Female		
	N	RMSE	AICc	N	RMSE	AICc	N	RMSE	AICc
Weight, kg									
Logistic	5,714	12.60	187.10	2,382	16.54	208.40	3,332	13.32	317.60
Gompertz	5,714	8.73	93.87	2,382	12.30	112.10	3,332	9.61	179.00
Von Bertalanffy	5,714	9.28	56.21	2,382	10.66	84.68	3,332	8.26	136.30
Brody	5,714	6.10	49.54	2,382	7.60	57.19	3,332	6.63	72.85
Height, cm									
Logistic	3,295	1.82	11.17	1,480	2.74	11.55	1,815	1.91	15.47
Gompertz	3,295	1.57	10.22	1,480	2.55	10.55	1,815	1.66	14.35
Von Bertalanffy	3,295	1.50	9.93	1,480	2.48	10.24	1,815	1.58	14.00
Brody	3,295	1.33	9.41	1,480	2.35	9.68	1,815	1.42	13.33

in estimating weight and height for all, male and female PC. The model had the lowest RMSE values for weight (6.10, 7.60 and 6.63, for all, male and female PC, respectively) and 1.33, 2.35, and 1.42 for height in all, male and female PC, respectively. Aside from lowest RMSE, the model also had the lowest AIC values for weight (49.54, 57.19 and 72.85, for all, male and female, respectively) and 9.41, 9.68 and 13.33 for height in all, male and female PC, respectively.

Figure 1 shows the different growth curves for all, male and female weight of PC using the four nonlinear model of Logistic, Gompertz, Von Bertalanffy and Brody. The inflection points of the different models differ from each other. The models of Von Bertalanffy, Logistic and Gompertz, but not Brody model, tend to overestimate weight at birth. The same result was observed in both male and female PC. The Brody model was found to be the best fit growth model for weight and the best model for estimating weight based on age.

All the points plotted in the four nonlinear models were observed to have overestimation and underestimation of height (Figure 2). The biggest overestimation was observed in Logistic and Gompertz for all body height. For the male height, there is an underestimation at age 51 to 57 months. Missing data at age 54 were not estimated to plot in the model for all, male and female body height. The Brody model had the best goodness of fit for all, male and female PC body height estimation using age.

Table 4 shows the parameter estimates of mature weight (W_∞) and height (H_∞), weight (W_0) and height (H_0) at birth and maturity index (*k*) obtained from four nonlinear models. The Brody model estimated the largest mature weight (601.32 kg, 1,074.10 kg and 561.13 kg respective to all, male and female PC) while the smallest values were obtained from the Logistic model (436.01 kg, 425.81 kg and 516.45 kg respective to all, male and female PC) for the body weight of PC. On the other hand, for growth in height, Brody model estimated the largest mature height (119.46 cm, 119.05 cm and 122.14 cm respective to all, male and female PC) and the smallest values were obtained for the Logistic model (118.55 cm, 120.89 cm and 118.16 cm respective to all, male and female PC).

Weights (W_0) and heights (H_0) at birth showed that the Brody model gave the lowest values compared to the other models and are very near to the actual average birth weight and height of PC. The W_0 for all, male and female PC are 30.02 kg, 35.97 kg and 31.19 kg, respectively, while the actual average birth weights for all, male and female PC are 29.5 kg, 29.8 kg and 29.3 kg, respectively. While, the H_0 for all, male and female are 67.8 cm, 68.2 cm and 67.3 cm compared to the actual average H_0 of 69.17 cm, 70.25 cm and 68.64 cm.

Maturity index (*k*) refers to the rate at which body weight approaches mature weight (Teleken *et al*., 2017). The smaller the value of *k* means the animal matures late while early maturing animals has a bigger *k* value (Ersoy *et al*., 2007; Gbangboche *et al*., 2008). The Logistic model for weights of PC estimated the largest *k* value 0.08 kg, 0.07 kg and 0.08 kg for all, male and female PC, respectively, while Brody model estimated the lowest *k* value of 0.02 kg, 0.01 kg and 0.02 kg respective to all, male and female PC. For the body height of PC, Logistic model obtained the highest *k* values of 0.10 cm, 0.09 cm and 0.10 cm for all, male and female PC, respectively, while the Brody model had the lowest and similar *k* values for all, male and female PC (0.07 cm). Thus, the higher the *k* value, the faster the animal gets close to its asymptotic weight (Garnero *et al*., 2005).

The predicted weights of PC using Brody model for all, male and female animals are presented in Table 5. The percent difference of the estimated weights ranged from 0.0

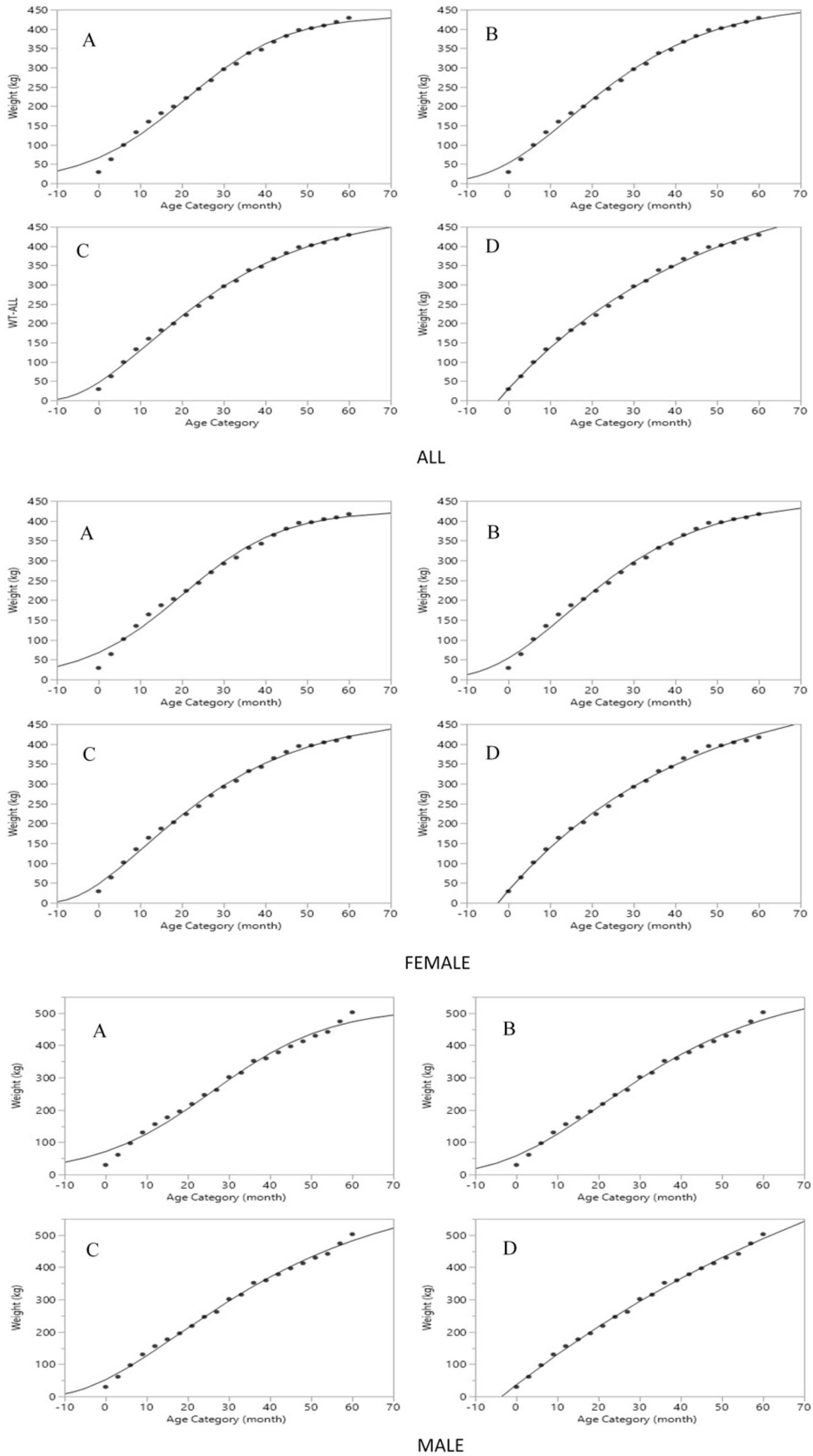

Figure 1. Growth curve for weight (kg) of all, female and male PC using nonlinear model of Logistic (A), Gompertz (B), Von Bertalanffy (C) and Brody (D).

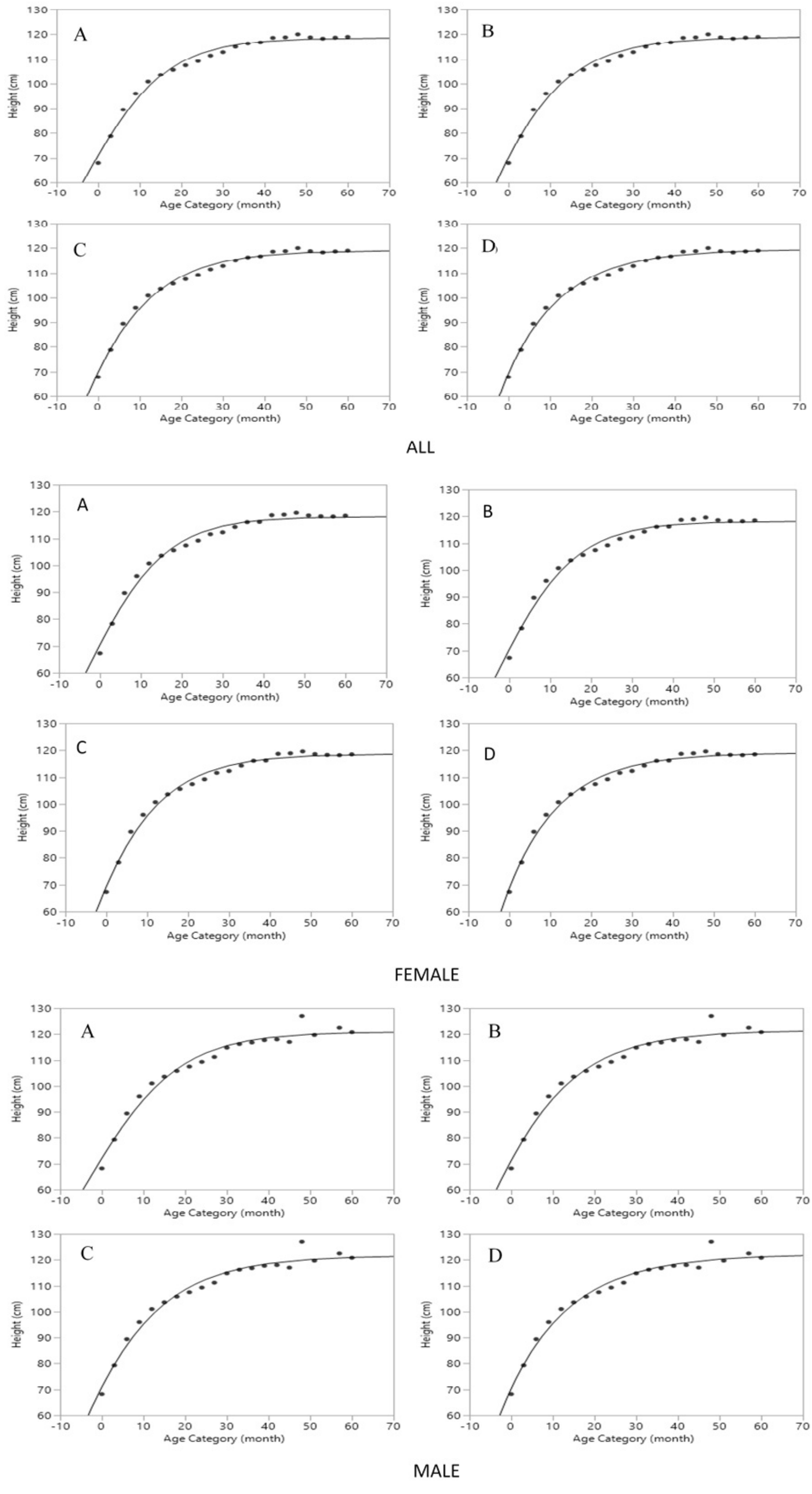

Figure 2. Growth curve for height (cm) of all, male and female PC using nonlinear model of Logistic (A), Gompertz (B), Von Bertalanffy (C) and Brody (D).

Table 4. Parameter estimates of W_∞, W_0, H_∞, H_0 and *k* obtained from four nonlinear models.

Mathematical Model	Overall			Male			Female		
	W_∞[1]	W_0[1]	*k*[1]	W_∞[2]	W_0[2]	*k*[2]	W_∞[3]	W_0[3]	*k*[3]
Weight, kg									
Logistic	436.01	66.07	0.08	516.45	70.10	0.07	425.81	67.55	0.08
Gompertz	468.32	52.50	0.05	587.88	57.82	0.04	453.80	53.88	0.05
Von Bertalanffy	490.33	44.88	0.04	643.25	51.74	0.03	472.35	47.52	0.04
Brody	601.32	30.02	0.02	1,074.10	35.97	0.01	561.13	31.19	0.02
Height, cm	H_∞[4]	H_0[4]	*k*[4]	H_∞[5]	H_0[5]	*k*[5]	H_∞[6]	H_0[6]	*k*[6]
Logistic	118.55	70.93	0.10	120.89	72.09	0.09	118.16	70.44	0.10
Gompertz	118.93	70.07	0.08	121.42	71.2	0.03	118.54	69.56	0.09
Von Bertalanffy	119.10	69.77	0.08	121.63	70.89	0.07	118.69	69.26	0.08
Brody	119.46	69.17	0.07	122.14	70.25	0.07	119.05	68.64	0.07

[1]5,714 number of observations
[2]2,382 number of observations
[3]3,332 number of observations
[4]3,295 number of observations
[5]1,480 number of observations
[6]1,815 number of observations

or almost 100% exact prediction of the actual weight to 20.7% in the predicted weight of male PC at birth. There is a high degree of accuracy in predicting the weight using the Brody model for all regardless of sex with an average difference of 2.4% or 97.6% accuracy. The highest percent difference of 6.5 was observed in weight at 9 months of age. For 12, 24, 36, 48 and 60 months old PC, the accuracy was computed to be 94.9%, 98.8%, 95.7%, 96.2% and 99.97%, respectively. When animals are sold at 36 to 48 months, adjustment weights 10 to 15 kg (3% to 5%) should be added in order to estimate the weight accurately.

The predicted height for all, male and female PC is shown in Table 6. The predicted height at birth, 21, 24, 27 and 30 months old were overestimated from actual height with a prediction difference of -1.4, -0.4, -0.9, -0.5 and -0.5, respectively. The percent difference of predicted to actual height ranged from 97% to 100% accuracy from birth until 60 months of age regardless of sex. For 12, 24, 36, 48 and 60 months old, the accuracy were found to be 97%, 99.2%, 99.2%, 98.1% and 99.8%, respectively. Thus, this shows a very good prediction of body height of PC using Brody model.

Correlation of body weight was determined with other variables including Age-Cat, HG and BL. Using separate linear regressions, among the morphometric variables, HG obtained higher R^2=0.895 followed by BL with R^2=0.885 and Age-Cat with R^2=0.883. The body weight was highly correlated with HG in cattle as reported by Bagui and Valdez (2007) and Tariq *et al*. (2013). Results obtained from live weight estimation in buffaloes also showed HG has the highest correlation with BW followed by BL (Singh *et al*., 1994; Abdelhadi and Babiker, 2009).

Multiple linear regression of body weight on three body measurement parameters (Age-Cat, HG and BL) was performed to design a body weight prediction model (Table 7). The model used was $BW = \alpha + \beta_1(\text{Age-Cat}) + \beta_2(BL) + \beta_3(HG)$, with $R^2 = 0.94$. The result of the present study concurs with Yan *et al*. (2009) where HG and BL were appropriate parameters for prediction of body weight in cattle.

The percent difference of predicted body weights of PC ranged from 0.5% to 42.8% of the actual body weights (Table 8). The highest percent difference of 42.8% and 11.8% was observed at birth (0 month) and at 36 months of age, respectively. Calves in pasture area are difficult to weigh and measure at exact age (0 month or at birth) which resulted in a large variation in the data set. Other sources of inaccurate prediction are due to the number of available samples in the data set and errors in measuring or recording of values in the data set. The highest degree of accuracy in predicting weight was observed at 22 to 33 months of age (1.1% to 2.4%).

The prediction equation of body weight for PC was validated using new set of data (Table 9). Predicted body weight was generated using the prediction equation:

$$BW= -131.377244 + 2.818707(\text{Age-Cat}) + 1.095026(BL) + 1.150713(HG)$$

The percent difference of predicted weight from actual weight ranged from 0.1% to 6.7% or 93.3% to almost 100% accuracy. This indicates a very good prediction of body weight. However, weight at 48 months showed low precision, and this can be due to errors in measurement.

In summary, the study shows that the PC is physiologically mature at 24 months, though the recommended body weight of 300 kg for breeding was attained at 30 months old for male and 33 months old for female. There is a significant increase ($P<0.05$) in weight

Table 5. Predicted weight (kg) using Brody model for all, male and female PC at different age category.

Age Category (Month)	Brody Model											
	All				Male				Female			
	N	Actual	Predicted	% Difference	N	Actual	Predicted	% Difference	N	Actual	Predicted	% Difference
0 (At Birth)	260	29.5	30.0	1.7	133	29.8	36.0	20.7	127	29.3	31.2	6.5
3	467	62.6	63.3	1.1	243	61.2	66.7	8.9	224	64.2	62.1	3.3
6	668	99.5	94.6	4.9	348	97.1	96.4	0.7	320	102.0	91.1	10.7
9	636	132.7	124.1	6.5	329	130.4	125.3	3.9	307	135.2	118.5	12.4
12	609	160.1	151.9	5.1	305	156.1	153.4	1.8	304	164.1	144.3	12.1
15	334	182.1	178.1	2.2	171	177.1	180.6	2.0	163	187.3	168.5	10.0
18	304	199.3	202.7	1.7	154	195.7	207.0	5.8	150	203.0	191.4	5.7
21	285	221.4	225.9	2.0	130	218.6	232.6	6.4	155	223.7	212.9	4.8
24	251	244.9	247.8	1.2	98	246.8	257.5	4.3	153	243.7	233.2	4.3
27	273	267.1	268.4	0.5	109	262.2	281.6	7.4	164	270.4	252.3	6.7
30	196	295.9	287.8	2.7	74	301.9	305.0	1.0	122	292.3	270.3	7.5
33	209	310.1	306.0	1.3	70	315.3	327.8	4.0	139	307.5	287.2	6.6
36	143	337.8	323.2	4.3	41	352.1	349.8	0.6	102	332.0	303.2	8.7
39	184	346.6	339.4	2.1	44	359.8	371.2	3.2	140	342.5	318.2	7.1
42	134	367.1	354.7	3.4	25	378.6	392.0	3.5	109	364.5	332.3	8.8
45	117	382.1	369.0	3.4	13	397.1	412.2	3.8	104	380.2	345.7	9.1
48	113	397.5	382.6	3.8	16	412.7	431.7	4.6	97	395.0	358.2	9.3

Table 5. Continued...

Age Category (Month)	Brody Model											
	All				Male				Female			
	N	Actual	Predicted	% Difference	N	Actual	Predicted	% Difference	N	Actual	Predicted	% Difference
51	156	402.3	395.3	1.7	27	429.9	450.7	4.8	129	396.6	370.0	6.7
54	133	409.1	407.3	0.4	17	441.9	469.1	6.2	116	404.3	381.2	5.7
57	128	418.6	418.6	0	19	474.3	487.0	2.7	109	408.8	391.6	4.2
60	114	429.1	429.2	0	16	502.7	504.4	0.3	98	417.0	401.5	3.7

N = Number of animals

Table 6. Predicted height (cm) using Brody model for all, male and female PC at different age category.

Age Category (Month)	Brody Model											
	All				Male				Female			
	N	Actual	Predicted	% Difference	N	Actual	Predicted	% Difference	N	Actual	Predicted	% Difference
0 (At Birth)	220	67.8	69.2	2.0	113	68.2	70.3	3.0	107	67.3	68.6	2.0
3	388	78.8	78.7	0.1	188	79.3	80.1	1.0	200	78.3	78.2	0.1
6	571	89.5	86.4	3.4	284	89.4	88.0	1.5	287	89.7	85.9	4.2
9	545	96.0	92.7	3.5	268	96.0	94.5	1.6	277	96.0	92.2	4.0
12	519	100.8	97.7	3.0	248	101.0	99.7	1.2	271	100.7	97.3	3.4
15	184	103.6	101.9	1.7	82	103.6	104.0	0.4	102	103.6	101.4	2.1
18	168	105.7	105.2	0.5	76	105.8	107.4	1.5	92	105.6	104.8	0.8

Table 6. Continued...

Age Category (Month)	Brody Model											
	All				Male				Female			
	N	Actual	Predicted	% Difference	N	Actual	Predicted	% Difference	N	Actual	Predicted	% Difference
21	148	107.5	107.9	0.4	54	107.5	110.2	2.5	94	107.4	107.5	0.1
24	132	109.2	110.1	0.8	45	109.3	112.5	2.9	87	109.2	109.7	0.4
27	103	111.4	111.9	0.4	39	111.2	114.3	2.8	64	111.6	111.4	0.1
30	19	112.8	113.3	0.4	4	114.8	115.8	0.9	15	112.3	112.9	0.5
33	80	115.0	114.5	0.5	29	116.2	117.0	0.7	51	114.3	114.0	0.2
36	23	116.3	115.4	0.8	8	116.8	118.0	1.0	15	116.1	115.0	1.0
39	67	116.7	116.2	0.4	22	117.7	118.8	0.9	45	116.2	115.8	0.4
42	7	118.6	116.8	1.5	1	118.0	119.4	1.2	6	118.7	116.4	2.0
45	12	118.8	117.3	1.3	1	117.0	119.9	2.5	11	118.9	116.9	1.7
48	22	120.0	117.7	1.9	1	127.0	120.3	5.2	21	119.6	117.3	1.9
51	45	118.8	118.0	0.6	11	119.7	120.7	0.8	34	118.6	117.6	0.8
54	4	118.3	118.3	0.0	0	0.0	0.0	0.0	4	118.3	117.9	0.3
57	17	118.7	118.5	0.1	57	122.5	121.2	1.1	15	118.2	118.1	0.1
60	21	119.0	118.7	0.2	60	120.8	121.4	0.5	17	118.5	118.3	0.2

N = number of animals

Table 7. Multiple linear regression of body weight (BW) on three independent variables.

Parameter	Regression Model	α Value	β_1 Value	β_2 Value	β_3 Value	R^2
Age-Cat, BL and HG	$BW=\alpha + \beta_1(Age\text{-}Cat) + \beta_2(BL) + \beta_3(HG)$	-131.377244* ±8.26	2.818707* ±0.20	1.095026* ±1.09	1.150713* ±0.14	0.94

*significant at $P<0.05$, Age-Cat=Age Category, BL= Body Length, HG= Heart Girth

Table 8. Estimation of body weight at different age category using the prediction equation $BW=\alpha+\beta_1(Age\text{-}Cat)+\beta_2(BL)+\beta_3(HG)$.

Age-Cat (month)	N	Actual WT (kg)	Predicted WT (kg)	SE	% Difference
0 (At Birth)	16	28.3	16.2	10.3	42.8
3	42	57.1	56.0	7.7	2.0
6	74	93.6	99.5	5.2	6.2
9	78	127.4	132.8	4.9	4.2
12	59	153.2	157.2	5.0	2.6
15	14	172.2	180.4	5.1	4.8
18	13	184.5	193.2	4.4	4.7
21	20	207.5	212.6	4.3	2.4
24	9	232.6	228.2	4.1	1.9
27	5	248.1	251.5	4.6	1.4
30	4	268.0	265.1	4.0	1.1
33	8	291.1	288.0	7.4	1.1
36	1	340.0	299.7	6.2	11.8
39	4	322.8	315.2	4.6	2.3

Table 8. Continued...

Age-Cat (month)	N	Actual WT (kg)	Predicted WT (kg)	SE	% Difference
45	1	310.5	331.0	10.4	6.6
48	1	333.5	333.2	7.4	0.1
51	2	343.5	356.4	7.5	3.8
60	1	419.5	417.3	9.1	0.5

Table 9. Prediction of body weight (BW) using new set of data for validation.

Animal ID	Sex	Date of Birth	Breed	Date	Actual WT(kg)	Age	Predicted WT(kg	% Difference
1CS18013	M	26-Feb-18	PC	26-Feb-18	21.0	0	19.6	6.7
1CS17030	M	20-Nov-17	PC	31-Jan-18	40.5	3	41.4	2.2
1CS17017	M	29-Sep-17	PC	31-Jan-18	97.0	6	101.9	5.1
1CS17012	F	15-Sep-17	PC	30-Apr-18	166.0	9	166.7	0.4
1CS17006	M	12-May-17	PC	30-May-18	200.0	12	200.2	0.1
1CS16022	M	25-Aug-16	PC	28-Feb-18	223.5	18	217.1	2.9
1CS16025	M	9-Sep-16	PC	30-Jun-18	210.0	21	213.3	1.6
1CS15028	M	23-Dec-15	PC	30-Jun-18	236.0	30	249.0	5.5
1CS14011	F	2-Apr-14	PC	31-Mar-18	250.0	48	336.6	34.6
1CS13018	F	28-May-13	PC	30-May-18	354.5	60	371.7	4.9

from birth until 60 months of age whereas the ADG only increased from 3 months old (0.36 kg/day) to 9 months old (0.38 kg/day) and then gradually slows down in 12 months up to 60 months of age. Height of PC increased significantly (P<0.05) as the animal grows from 0 (at birth) until 12 months old.

The study concludes that Brody Growth Curve Model best fit the data set of weight and height for all, male and female PC. There is a high degree of accuracy in predicting the weight using the Brody model for all PC regardless of sex with an average difference of 2.4% or 97.6% accuracy. The percent difference of predicted to actual height ranged from 97% to 100% accuracy from birth until 60 months of age regardless of sex.

Among morphometric variables, significantly higher correlation of body weight (BW) was found with HG, followed by BL. The model for predicting body weight is BW = -131.377244 + 2.818707(Age-Cat) + 1.095026(BL) + 1.150713(HG). A higher degree of accuracy in predicting weight was observed in 22 to 33 months of age (1.1% to 2.4%). Using the validation data, the percent difference of predicted weight from actual weight ranged from 0.1% to 6.7% or 93.3% to almost 100% accuracy, indicating that the model is very good in predicting body weight.

Prediction of body weight using growth curve and linear regression may be used to monitor the growth of animals, determine dosage required in administering medicine, feed requirements and provide estimated weight of animals when sold to the market.

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