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Growth Curve of Amazonian Manatee (*Trichechus inunguis*) in Captivity

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Abstract

The objective was to describe the growth curve for Amazonian manatees (*Trichechus inunguis*) raised in a captive facility in the Peruvian Amazon. We collected data on age (in months), body weight (BW; kg), and curved total length (CTL; cm) as biometric measurements of four rescued manatees (two males and two females). We used the Simple Gompertz equation to model the data and obtain a growth curve estimate. From the evaluated manatees, growth rates were estimated by sex: (1) for males, the growth rate was 0.11 kg/mo and 0.06 cm/mo, reaching an asymptotic BW of 100.06 kg and CTL of 196.31 cm; and (2) for females, the growth rate was 0.09 kg/mo and 0.06 cm/mo, with an asymptotic BW of 131.52 kg and CTL of 207.40 cm. The age at the maximum speed of weight and CTL growth for males was around 17.97 to 17.44 mo old, and 21.93 to 16.81 mo old for females. The Gompertz equation was a good mathematical model to describe the growth rate of the Amazonian manatee.

Key Words: Amazonian manatee, *Trichechus inunguis*, Gompertz function, growth modelling, maturity age

Introduction

The Amazonian manatee (*Trichechus inunguis*) is a freshwater sirenian endemic of the Amazon, distributed in Peru, Colombia, Brazil, Ecuador, and Guyana (Domning, 1982; Best, 1984; Timm et al., 1986). In Peru, this species is highly threatened by hunting (Reeves et al., 1996), which is referenced in Appendix II of CITES; is listed as "Vulnerable" by the International Union for Conservation of Nature (IUCN); and is listed as a "Protected Amazon Species" under the Regulation of Fishing Ordering of the Peruvian Amazon (Rosas, 1994). Indiscriminate exploitation of this species and its habitat provided cause for the creation of rescue centers to assist individual manatees and allow for the study of this species and improvement of conservation strategies (Calvimontes, 2009). The development of growth models for individuals in wild populations has benefited the comprehension of animal ecology (Eaton & Link, 2011), population biology, and individual growth patterns of different species. Traditionally, to estimate growth models, it is common to use non-linear regressions of total length (TL), curved total length (CTL), or body weight (BW) with the age of an individual, but these methods do not consider inter-individual variability (Kimura, 1980; Cailliet & Goldman, 2004). Many of these models can estimate age of the animals to understand different aspects such as growth rate, age of maturity, and life expectancy, among other important factors, to increase knowledge of the biology of the species in the wild (Morris, 1972).

The Amazonian manatee is the smallest species of the Trichechidae family. In the wild, they can reach 300 cm in TL and 450 kg in BW (Rosas, 1994). There are reports of captive individuals reaching 266.5 cm in TL and 379.5 kg in BW (Amaral et al., 2010). Marsh (1980) conducted one of the first studies to estimate growth rates for sirenians by analyzing the layer of dental growth to predict the age of dugongs (*Dugong dugon*) using the von Bertalanffy growth function. Subsequently, Marmontel et al. (1996) and Brill et al. (2015) studied the growth layers of the ear bone of the Florida manatee (*Trichechus manatus latirostris*) to determinate animal age using the logistic function. Researchers widely use the ratio between TL and BW to monitor an individual animal's growth. In sirenians, different authors have established the relationship between BW and biometric measures for the dugong (Adulyanukosol et al., 2007), Florida manatee (Odell et al., 1978), and Amazonian manatee (Rosas et al., 2001; Amaral et al., 2010). In this last species, some researchers have described a high correlation between BW, TL, and CTL, showing it is possible to use the TL and CTL as predictors of BW (Mendoza et al., 2017). Colares (2002) used the Gompertz model to describe a growth curve (CTL-age) for the Amazonian manatee in captivity; and recently, use of the von Bertalanffy equation allowed description of the growth curve (CLT-age) of this species in the wild (Vergara-Parente et al., 2010).

The objective of this study was to describe the growth curve of the Amazonian manatee in captivity using the Gompertz model with CTL-age and BW-age, with the purposes of contributing to a better understanding of the biology and ecology of the species, to facilitate handling in captivity, and to assist with its conservation.

Methods

Facilities and Management Practice

The present study used the facilities of the Amazon Rescue Center (CREA, for its acronym in Spanish), which is located in the Amazon forest (Iquitos, Peru), a region that includes the natural habitat of the Amazonian manatee. The facilities are a suitable structure for monitoring and management of rescued animals kept in captivity, with the objective to conserve this species. The animals experienced conditions with a mean environmental temperature of 28.8°C, while water temperature in the breeding pools was maintained between 23 and 31°C.

Animals and Data Collection

Rescued animals less than 1 year old were monitored during three different stages during a 51-mo evaluation period from their rescue in captivity. These stages included (1) adaptation to captivity, (2) weaning, and (3) pre-release. Our sample of observed, stranded, very young individuals included four manatees (two males and two females) in good health, who exhibited a seemingly normal growth pattern under these captive conditions.

The rehabilitation and subsequent release of rescued animals in a reserve within their natural habitat was a priority. For this reason, age was only estimated via non-invasive methodologies. We estimated individual age at rescue by observing the vestige of the umbilical cord and its state of healing using the presence of the fresh umbilical cord as reference to animals under 2 mo of age.

Our observation period was ~51 mo, during which we recorded monthly biometric measurements of all four study animals: body weight (BW ± 0.01 kg) and the curved total length (CTL ± 1.00 cm) on the dorsal line from the anterior cranium to the tail end.

Statistical Analyses

We used a non-linear growth model of the Gompertz function with the PROC NLIN and the Quasi-Newton method in the statistical software *Statistica*, Version 7, to analyze the data. The Gompertz mathematical model follows:

$$BW = BWo + a_i * Exp(-Exp(-b_i(Age - c_i)))$$

$$CTL = CTLo + a_i * Exp(-Exp(-b_i(Age - c_i)))$$

Where the equation components are defined as BW is body weight (kg), CTL is curved total length (cm), BW_0 is body weight at birth (kg), CTL_0 is curved total length at birth (cm), age is in months, a_1 and a_2 are body weight (kg) and curved total length (cm) at maturity, b_1 and b_2 are growth rate in BW (kg/mo) and CTL (cm/mo), and c_1 and c_2 are age at inflection point BW and CTL growth. The asymptotic value comes from the sum of the increment (a_i) and the initial value (BW_0 or CTL_0).

Results

At the start, when each manatee was first rescued, the males averaged 101 cm for CTL and 15.10 kg for BW, while females presented 103 cm for CTL and 14 kg for BW on average. Their estimated initial ages were 6 and 8 mo for males and females, respectively. The last recorded biometric measurements for these manatees were 196.31 cm (CTL) and 100.06 kg (BW) for males at 47 mo, and 207.40 cm (CTL) and 131.52 kg (BW) for females at 51 mo. The periodic measurement data of both parameters are described in Appendix 1.

From the Gompertz equation, growth curves calculated for male and female manatees from an identified age to estimate the BW were

$$BW = 7.5 + 92.561 * Exp(-Exp(-0.1105\ (Age - 17.973)))$$

with ($R^2 = 0.991$) for male.

$$BW = 8.1 + 123.42 * Exp(-Exp(-0.0872\ (Age - 21.934)))$$

with ($R^2 = 0.970$) for female. (Figure 1)

The growth curves obtained from age and the CTL for male and female manatees were

$$CTL = 76 + 120.31 * Exp(-Exp(-0.0616\ (Age - 16.812)))$$

($R^2 = 0.982$) for male.

$$CTL = 71 + 136.404 * Exp(-Exp(-0.0617\ (Age - 17.437)))$$

($R^2 = 0.938$) for female. (Figure 2)

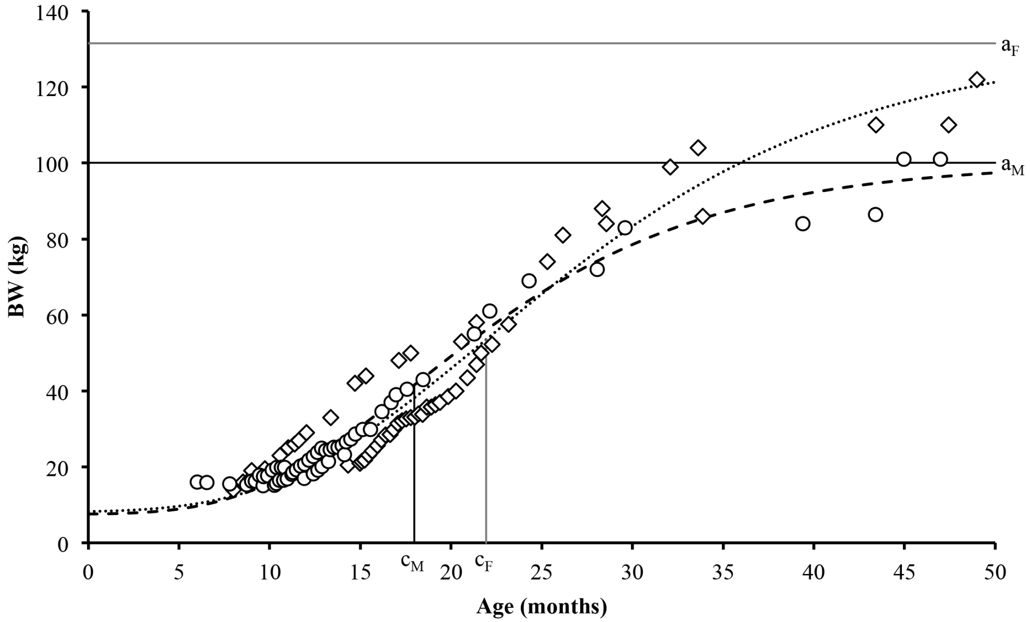

Figure 1. Curve of growth of body weight (BW) of expected value in males (**---**) and females (···) obtained for Gompertz equations and observed values for males (○) and females (◊); from the age in months of Amazonian manatees kept in captivity. BW at maturity ($a_M = BW_0 + a_1$ and $a_F = BW_0 + a_1$); c_M and c_F: age at maximum growth speed of the BW of each sex.

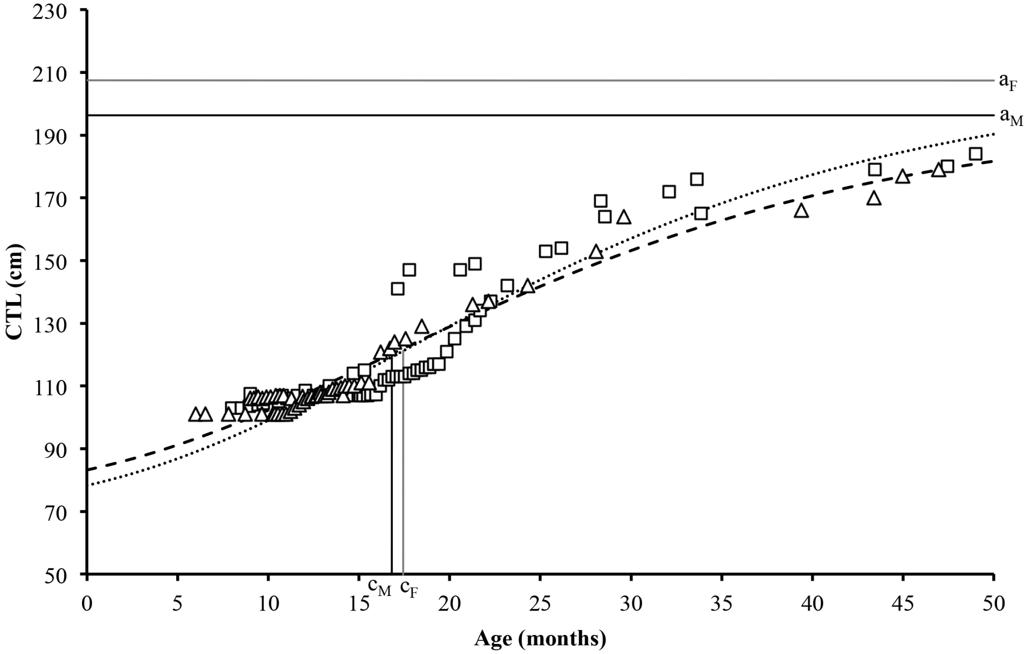

Figure 2. Curve of growth of the curved total length (CTL) of expected value in males (**---**) and females (···) obtained for Gompertz equations and observed values for males (**Δ**) and females (□); from the age in months of Amazonian manatees kept in captivity. CTL at maturity ($a_M = BW_0 + a_2$ and $a_F = BW_0 + a_2$); c_M and c_F: age at maximum growth speed of the CTL of each sex.

Table 1. Obtained parameters using the Gompertz model to describe the adjusted growth for body weight (BW) and curved total length (CTL) in females and males

Sex	Parameter	a_1	b_1	c_1
Female	BW	123.42	0.11	21.93
	CTL	136.40	0.06	16.81
Male	BW	92.56	0.09	17.97
	CTL	120.31	0.06	17.44

BW = body weight (kg), CTL = curved total length (cm), a_i = BW (kg) or CTL (cm) increase at maturity, b_i = BW or longitudinal growth rate, and c_i = age at maximum growth rate of BW or CTL (months old)

We obtained variables from the model to describe the adjusted growth rate for BW/age and CTL/age in females and males (Table 1). The model yielded weight at maturity ($BW_0 + a_1$) of 100.06 kg for males and 131.52 kg for females. With an adjustment of CTL/age, we obtained a CTL at maturity ($CTL_0 + a_2$) of 196.31 cm for males, and a closer estimate (207.40 cm) to the real measure for females.

The monthly growth rates (b_1 and b_2) were 0.11 kg/mo and 0.06 cm/mo for the males, and females showed a growth rate (b_1 and b_2) of 0.09 kg/mo and 0.06 cm/mo. A marked difference was seen in age between the sexes for a growth spurt (i.e., a maximum speed of body weight and length growth [c_1]): 17.97 and 21.93 mo old for males and females, respectively. Furthermore, age at maximum velocity of length growth (c_2) in the CTL observed for the sexes was close together: 17.44 and 16.81 mo old for males and females, respectively.

Discussion

Biometric Measurements

The measurable characteristics associated with animal growth and development can be described by using the non-linear sigmoidal functions (Colares, 2002). When describing the dimensional characteristics, such as body weight and length, however, each variable has certain limitations to express the growth. Rosas (1994) mentioned that the CTL is not a reliable measure since it can be variable between individuals with the same body straight length depending on its nutritional status. However, Colares (2002) and Vergara-Parente et al. (2010) agree with the importance of this measure for the description of manatee growth as a good indicator to monitor growth rates of individuals of this species. In addition, in Amazonian manatee calves, some researchers have described a close relationship between CTL and BW by a high correlation coefficient (Mendoza et al., 2017).

Birth Body Weight and Length Data

Best (1984) described a birth weight of Amazonian manatee calves to be between 10 to 15 kg and birth length to be between 85 to 105 cm. Also, the Aquatic Mammals Laboratory of the National Research Institute of the Amazon of Brazil (LMA/INPA, for its acronym in Portuguese) reported ranges of BW and TL at birth of 11 to 18 kg and 85 to 99 cm, respectively. However, Amaral et al. (2010) observed neonates of 7.5 kg and 76.0 cm for males and 8.1 kg and 71 cm for females, which were probably premature animals or animals that were affected by stress during pregnancy. These animals likely experienced similar conditions to our study animals, which is why we chose these data as our weight and length at birth for the growth model.

Body Weight and Curved Total Length at Maturity

The greatest values of BW and TL observed in wild and captive Amazonian manatees have ranged from 280 to 300 cm for TL and 400 to 450 kg for BW (Husar, 1978; Ayres & Best, 1979; Rosas, 1994). However, recent studies obtained lower values—for example, 236 cm in Albuquerque (2003), and 255.5 cm and 346.5 kg for males and 266.5 cm and 379.5 kg for females in Amaral et al. (2010). These values are greater than the values we recorded of 196 cm and 100.06 kg for males and 207 cm and 131.52 kg for females. These lower values could be a result of their condition that led to their need for rescue—that is, the animals likely experienced food shortages that could have produced a state of initial nutritional deficiency limiting their development. Alternatively, Colares (2002) reported values closer to our data for both sexes using the Gompertz model, with weights at maturity of 161 and 172 kg for males and females, respectively, and with CTLs of 217 cm for males and 215 cm for females. This similarity in values could be related to the use of the same mathematical model and that all study animals were captive, which is the main difference between previous studies that work with animals both in the wild and in captivity.

Vergara-Parente et al. (2010), using the von Bertalanffy equation, observed that wild Amazonian manatees reached a maximum CTL of 299.0 cm in males and 256.1 cm in females, which are higher values than in this study. Factors such as the type of mathematical function that we used, the capacity of these mathematical models to explain, and the physiological concordance of development, as well as the age of the evaluated individuals, could explain these differences.

Captivity Effect

The different management conditions (captivity and/or wild) might also influence the data variability. Borges et al. (2012) evaluated the first 2 years of life of two manatee (*T. manatus*) groups from the Antilles. The first group included neonates rescued from the wild without their mothers and kept in captivity, while the second group were neonates born in captivity and maintained with their mothers. They observed a significant difference in the growth pattern between the groups during the first year, with an increase in weight and body length greater in the neonates born in captivity with maternal lactation. At the end of the first year, the animals of the second group reached a weight close to twice the weight reached by calves of the first group. The data obtained from the Amazonian manatee presented the same difference in the growth pattern: the quality of the diet offered in captivity can positively influence growth rates for captive animals (O'Regan & Kitchener, 2005; Borges et al., 2012).

Sexual Dimorphism

Some reports of Amazonian manatees have described an absence of sexual dimorphism and no difference in length-weight relationship between sexes (Rosas, 1992; Amaral et al., 2010; Borges et al., 2012; Harshaw et al., 2016). Alternatively, Santana (2003) revealed that the Antillean manatee presents significant morphometric differences between sexes in captivity from weaning to sexual maturity. In the present study, we observed the female weight was greater than the male weight, though caution is noted because of our low sample sizes. The CTL did not show a significant difference, though females were longer than males at the same age; this pattern was also observed by Vergara-Parente et al. (2010). These observations agree with Colares (2002) who described that in the Antillean manatee, the most long-lived animals are females who are heavier, which suggests that sex influences the development pattern of the species. Likewise, females of the Florida manatee are usually heavier than males (Marsh et al., 2011). Silva (1998) suggests that females should be heavier and longer to store the necessary reserves to cope with pregnancy and lactation, which is similar to mysticete cetaceans.

In the Amazonian manatee, some authors have observed that females tend to grow faster than males, either in the wild or in captivity (Albuquerque, 2003; Vergara-Parente et al., 2010), in the same way females of the Florida manatee tend to have a faster weight and length increase than males (Harshaw et al., 2016). All this agrees with the observations of the present study in which weight differences between the sexes increased with the increase of the curved length and with age.

Growth Rate by Sex

Individual growth rates are an important parameter to consider when studying any species. Albuquerque (2003) described a growth rate for Amazonian manatees in captivity of 0.21 cm for males and 0.33 cm for females. Likewise, Vergara-Parente et al. (2010) observed wild growth rates of 0.09 cm for males and 0.24 cm for females. In contrast to previous evaluations, the present study did not observe differences in the average growth rate between males and females; however, when observing the growth curves, we can see a tendency for females to possess length and weight growth rates greater than males for approximately the first 2 years of their lives.

The *T. inunguis*, like the other individuals of the Trichechidae family, present a polygamous reproductive system, which likely causes a high-energy demand in males, especially for small males (Pereira, 1944; Marmontel et al., 1992). Although males reach sexual maturity between 4 to 9 years of age (Amaral et al., 2017), they need to continue growing to be physiologically mature to reach a body size that will allow them to compete with other males for access to females (Senger, 2005; Baker et al., 2010). Likewise, although females achieve sexual maturity between 2.5 to 7 years of age (Amaral et al., 2017), they continue to grow to reach the physiological maturity to endure a long gestation of 11 to 13 mo. That suggests that in the Amazonian manatee, sexual and physiological maturity do not happen at the same age—they reach sexual maturity earlier than physiological maturity (Senger, 2005; Baker et al., 2010). In the present study, the two males presented a maximum growth speed in weight and length at a younger age than the females, probably because size at physiological maturity of the males is lower than females, which requires a shorter time to be reached.

Growth Studies of Aquatic Mammals

There are just a few studies of growth in the Amazonian manatee, which makes it difficult to compare the data with other studies. However, it is an aspect that can help to understand better the ecology and biology of the species, which is encouraging to further study of the topic. Alternatively, for the Amazonian manatee, dental analysis is likely not accurate enough to determine age because they present horizontal replacement of the teeth via reabsorption and redeposition of the bone (Domning & Hayek, 1984). Likewise, study of the growth layers (GLG) of the ear bone for the same purpose is limited in live animals because it often requires the slaughter of the animals. Thus, it is necessary to do more research to develop methodologies that allow estimation of individual age by non-invasive methods that allow for easy application in the management of this species in captivity and/or in the wild.

Growth studies of different species of aquatic mammals such as bottlenose dolphin (*Tursiops truncatus*; Gol'din & Gladilina, 2015), monk seals (*Monachus monachus*; Murphy et al., 2012), and dolphins in southeastern Brazil (*Stenella frontalis* and *Delphinus* sp.; Siciliano et al., 2007) have used the Gompertz equation as a common method. In the same way, other studies have used the Gompertz and von Bertalanffy equations simultaneously in species such as franciscana dolphins (*Pontoporia blainvillei*; Botta et al., 2010), Steller sea lions (*Eumetopias jubatus*; Winship et al., 2001), New Zealand sea lions (*Phocarctos hookeri*; Childerhouse et al., 2010), and a variety of pinnipeds (McLaren, 1993). Use of the von Bertalanffy equation to evaluate growth of the tucuxi dolphins (*Sotalia fluviatilis*; Santos et al., 2003) and Baikal seals (*Pusa sibirica*; Amano et al., 2000) has also been completed. Regarding this type of study in sirenians, the von Bertalanffy equation is not a common method, and its application has not had satisfactory results (Colares, 2002; Albuquerque, 2003), with the exception of Vergara-Parente et al. (2010) who used the von Bertalanffy equation and concluded adequate results for establishment of a growth curve in wild Amazonian manatees.

In the present study, the Gompertz model adequately described the growth of the Amazonian manatee in captivity, which could suggest that the Gompertz model is a good tool to describe the growth of the Amazonian manatee generally. It can be a great method to estimate growth pattern models and growth rates of this species.

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Appendix 1. Periodic measurement data of body weight (BW) and curved total length (CTL)

Female				Male			
Animal	Age	BW (kg)	CTL (cm)	Animal	Age	BW (kg)	CTL (cm)
Animal 1	9.00	19.00	107.50	*Animal 3*	6.00	16.00	101.00
	10.77	19.20	107.00		6.53	15.90	101.00
	12.50	20.50	107.00		7.80	15.50	101.00
	14.33	20.50	107.00		8.73	15.30	101.00
	14.97	20.90	107.00		9.63	15.10	101.00
	15.07	21.40	107.00		10.27	15.20	101.00
	15.23	21.80	107.00		10.37	15.60	101.00
	15.47	23.10	107.00		10.53	16.50	101.00
	15.67	24.20	107.20		10.77	16.50	101.00
	15.93	25.60	107.20		10.97	16.80	101.00
	16.17	27.10	110.00		11.23	18.10	102.00
	16.40	28.40	112.00		11.47	19.30	103.00
	16.63	28.50	112.00		11.70	20.20	104.00
	16.83	29.80	113.00		11.93	20.70	105.00
	17.07	31.40	113.00		12.17	21.80	106.00
	17.30	32.10	113.00		12.40	22.70	107.00
	17.53	32.60	113.00		12.63	23.80	107.00
	17.77	33.00	114.00		12.87	24.90	108.00
	18.00	33.10	114.00		13.10	24.30	107.00
	18.20	34.00	115.00		13.33	24.60	108.00
	18.43	33.80	115.00		13.53	25.20	109.00
	18.67	35.70	116.00		13.77	25.20	109.00
	18.90	35.80	116.00		14.00	25.70	109.50
	19.13	36.30	117.00		14.23	26.60	110.00
	19.40	36.90	117.00		14.47	27.30	110.00
	19.83	38.50	121.00		14.73	28.60	110.00
	20.27	40.00	125.00		15.13	29.80	111.00
	20.90	43.50	129.00		15.57	29.80	111.00
	21.40	47.00	131.00		16.20	34.50	120.80
	21.67	50.00	134.00		16.70	37.00	122.00
	22.27	52.20	137.00		16.97	39.00	124.00
	23.17	57.50	142.00		17.57	40.50	125.00
	25.30	74.00	153.00		18.47	43.00	129.00
	26.17	81.00	154.00		21.27	55.00	136.00
	28.33	88.00	169.00		22.13	61.00	137.00
	32.10	99.00	172.00		24.30	69.00	142.00
	33.63	104.00	176.00		28.07	72.00	153.00
	43.43	110.00	179.00		29.60	83.00	164.00
	47.43	110.00	180.00		39.40	84.00	166.00
	49.00	122.00	184.00		43.40	86.50	170.00
	51.00	122.00	189.00		44.97	101.00	177.00
Animal 2	8.00	14.00	103.00		46.97	101.00	179.00
	8.53	16.00	103.00	*Animal 4*	9.00	16.20	106.00
	8.97	17.00	103.50		9.20	16.20	106.00
	9.43	18.00	104.00		9.43	17.80	106.50
	9.73	19.50	104.50		9.67	17.50	106.00
	10.57	23.00	105.00		9.90	17.70	106.50
	11.03	25.00	106.00		10.13	19.10	106.50
	11.37	26.00	106.00		10.40	19.90	107.00
	11.60	27.00	107.00		10.63	19.90	107.00
	12.03	29.00	108.50		10.83	19.90	107.00
	13.37	33.00	110.00		11.27	18.50	106.00
	14.70	42.00	114.00		11.90	17.00	106.60
	15.30	44.00	115.00		12.40	18.20	106.60
	17.13	48.00	141.00		12.67	19.20	107.00
	17.77	50.00	147.00		12.90	20.10	107.00
	20.57	53.00	147.00		13.23	21.40	107.00
	21.40	58.00	149.00		14.13	23.20	107.00
	28.57	84.00	164.00				
	33.87	86.00	165.00				