

MODELING INDIVIDUAL ENERGY STATUS FOR IMPROVED ANIMAL MANAGEMENT

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Abstract

Energy use may represent the most direct gauge of physiological activity and thus relative nutrient requirements, however nutrient requirements are generally reported relative to intake or bodyweight, assumptions which make it difficult to confidently estimate nutrient targets for individuals and species. Managing energy balance in captive exotic animals is even more challenging due to the limitations of their environment including feed items and presentation. Recognizing these challenges and developing strategies and tools to overcome them in order to avoid negative impact on animal health and welfare is the responsibility of every institution managing captive animals. Historic weight, body condition, diet energy and intake data were used to estimate and track individual energy requirements for improved management of exotic felids in the Fort Worth Zoo collection. Weights and diet information were used to provide simultaneous estimates of average daily gain and average daily caloric intake. Simple linear regression of gain versus intake was used to calculate the maintenance energy requirement and caloric cost per gram of weight gain per day. These estimates were used to reduce food waste, manage body condition, control rates of weight gain or loss, and manage diets to avoid caloric drift. Continued evaluation using similar tools could help to quantify factors impacting energy requirements such as seasonal fluctuation or underlying health conditions.

Introduction

Nutrient requirements are determined by nutrient utilization in physiological processes. All biochemical reactions are driven by energy, therefore energy use may represent the most direct gauge of physiological activity. Nutrients requirements are typically stated in terms of dry matter intake (e.g. %DM or ppm) or bodyweight (g/kg BW or %BW) which are imperfect proxies for energy requirement. The assumptions inherent in these proxies become apparent when significant variation exists in the energy density of feeds, individual energy requirements, or individual body mass or fat mass. Corrections such as scaling to metabolic bodyweight, average intake on % bodyweight basis, estimated activity level, or weight at moderate body condition have been adopted to reduce these assumptions. However even with correction factors, numerous and sometimes circular assumptions add to the difficulty and imprecision of estimating nutrient targets for individuals and species (Table 1).

Energy balance also signals physiological function to adapt for survival, growth and reproduction. Thus energy balance is associated with changes in reproductive performance, susceptibility to infectious disease, and metabolic dysfunction. Due to the numerous associated health concerns, improper energy management of captive animals is increasingly recognized as an animal welfare issue.¹ Physiological adaptations to energy signals may occur as early as fetal

development, determining the physiological trajectory of offspring – including their reproductive fitness.² Managing animals to avoid energy imbalance (e.g. obesity or starvation) is therefore a significant concern for the health and welfare of animals and also for their success as a species.

Institutions with captive exotic animals face numerous challenges to managing appropriate energy balance including limited enclosure space and exercise opportunities, climate, compulsory group/social structure, and behavior requirements (e.g. shifting animals, encouraging foraging, avoiding stereotypy, minimizing aggression).³ Demand for certain desired behaviors such as medication compliance and shifting of animals may contribute to the use of unhealthy food rewards. Food is often fed in concentrated ‘meals’ creating feeding and fasting cycles. On top of this, food item types and variety may be limited by availability and tend to be more energy-dense and carbohydrate-rich – further altering energy signaling. All of these challenges influence the physiology of the animal and may further contribute to undesirable behaviors and health consequences.³ Recognizing these challenges and developing strategies and tools to overcome them is the responsibility of every institution managing captive animals.

Weight and body condition fluctuations were observed in several species of large cats at the Fort Worth Zoo. These fluctuations reflected overshoots following adjustments for weight gain, weight loss, or changes in animal intake (e.g. wasted food or perception of hunger). Historic weight, body condition, diet energy and intake data were used to estimate and track individual energy requirements – providing targets for managing animals at maintenance or for effecting desired weight and condition changes. Such targets could allow for reduced food waste and better control of individual energy balance. For example, if an animal begins leaving food these targets would indicate whether a diet reduction or an item substitution is warranted. Or, if weight gain is desired, individual energy targets might allow for greater confidence in feeding for slow, steady gains as well as an estimate of when target weight will be achieved. Finally, evaluating individual energy requirements and history can allow for the identification and quantification of factors impacting energy requirement such as seasonal fluctuation or underlying health conditions.

Materials and Methods

Diet information for individual animals was converted to average daily kcal (Table 2). Caloric intake information was then combined with the weight history of the animal to calculate corresponding average kcal/d and average daily gain (ADG) values (Table 3). When multiple weights were available between diet changes, ADG was calculated for the entire diet period using linear regression. When intake differed from offered diet, average kcal/d was adjusted for that period. Weights were plotted across time with corresponding body condition scores to illustrate the pattern and degree of fluctuations with corresponding caloric data overlaid (Figure 1). The change in bodyweight between subsequent measures was plotted against the average kcal/d consumed during the same period (Figure 2). Simple linear regression was used to model ADG versus average kcal/d intake. The x-intercept of this regression represents the estimated maintenance energy requirement (i.e. kcal intake where weight change = 0). The inverse of the slope represents the kcal cost for 1 g of weight gain. Example analysis for 3 older cats (0.1 *Panthera tigris jacksoni*, 17 years old; 1.0 *Panthera onca*, 14 years old; 1.0 *Acinonyx jubatis*, 15 years old) are reported here.

Results and Discussion

The maintenance energy requirements per kg metabolic bodyweight estimated for Fort Worth Zoo exotic felids using this method were similar to estimated requirements from intake studies in exotic felids and higher than values for domestic cats (Table 4).^{4,5,13} The maintenance energy requirement for FWZ 0.1 *Panthera tigris jacksoni* was the highest and may have been overestimated due to limited records on intake. This animal also had the highest caloric cost for gain. Interestingly, higher than expected energy requirements has been observed in other tiger subspecies compared to cheetah and lion.¹³ Differing energy requirements could be due to activity level, stress or underlying metabolic differences.¹³

The cost for 1 g of gain was between 6 and 17 kcal per g. If one assumes that gain equal parts fat (9.3 kcal gross energy/g) and protein (5.6 kcal gross energy/g) and 50% water and the energy efficiency of energy conversion is 65%,^{6,7} the cost per gram gain would be 5.7 kcal/g gain. Energetic costs for gain reported in the literature are 1.8 kcal/g in nursing kittens,^{6,8} 5.5 kcal/g in meat production goats,⁹ 6.2 kcal/g in growing black-bellied ducks,¹⁰ 13.1 kcal/g in women¹¹ and 20 kcal/g in late growth foals.¹² Differences in estimates must account for differences in the energy efficiency of feed items as well as the metabolic efficiency and composition of weight gain. For examples, animals in higher body condition lay down a higher proportion of gain as fat. The energy efficiency of carnivore feed conversion is expected to be greater than that of herbivorous or omnivorous species, while the metabolic disposition towards tissue gain in a mature animal may be less than that of a young growing animal.

Unfortunately many diet changes tend to be reactive rather than proactive: i.e. they occur following an undesirable observation (too thin!) and demand a rapid return toward the desirable. Quantitative predictions of weight changes on a given diet (kcal level) can allow managers to predict the time to reach a particular weight and make adjustments prior to reaching an undesirable condition. Such adjustments may be tailored for slow weight changes by providing reasonable expectations for gains following diet changes – as opposed to making multiple diet changes to ensure short term changes which then rapidly overshoot goals. For example, an increase of 500 kcal calories from 2800 kcal to 3300 kcal would be predicted to reverse weight loss from -40 g/day to a gain of 32 g/day or 1 kg per month.

Variation in average daily gain per kcal intake is multifactorial. The greatest contributor to variation in ADG is due to normal weight variation. Average daily weight changes are expected to be small, therefore a 1% difference in weight (e.g. due to scale error or normal variation in gut fill) could contribute to erroneous ADG values particularly for weights collected within a short timeframe. For this reason linear regression was used to describe the overall pattern of weight change on each diet; however this approach is only useful when multiple weights are collected within a diet period. Ideally weight data would be regular and frequent, and ADG estimations calculated from multiple weights during prolonged feeding of a single diet. Outliers and ADG values outside of ± 200 g/d should be evaluated for sources of mis-estimation.

Some variation is due to the assumptions in this approach. It was assumed that the diet amounts entered equal the amounts consumed. If the animal was leaving food, the calories required for

that period of gain would be overestimated. This approach also assumes a linear relationship between ADG and kcals consumed over time and body conditions. This approach also assumes there is no 'metabolic set-point' and is violated if the energy requirement of the animals is affected by factors such as lactation or change in body size. Variation in the relationship between ADG and kcal consumed may also be due to external factors such as seasonal metabolic changes, age-related changes, disease states, changes in activity level or altered animal management. For example, during a period of known inactivity due to enclosure restriction, the jaguar tripled his ADG with no change in caloric intake. Separating and quantifying these effects on energy utilization can provide important information about energy balance and managing animals.

This modeling approach could be especially valuable for species which lack good references for energy and nutrient requirements. Individual energy requirements could be estimated based on weight and diet records. The information could aid not only in the management of the animal's condition, but also provide an energetic basis for extrapolating other nutrient requirements when information from model species is insufficient.

Conclusions

Simple modeling techniques and basic management data (weights and diet records) can be used to predict energy balance for individual animals. These predictions can be used to establish improved individual targets for diet and weight or body condition changes and provide proactive management of captive exotic animals to avoid undesirable fluctuations in condition and diet.

Literature cited

1. Degeling C, Rock M, Teows L. Potrayals of canine obesity in English-Language newspapers and in leading veterinary journals, 2000-2009: Implications for Animal Welfare Organizations and Veterinarians as public educators. *J Appl Anim Welfare Sci* 2011;14:286-303.
2. Armitage JA, Taylor PD, Poston L. Experimental models of developmental programming: consequences of exposure to an energy rich diet during development. *J Physiol* 2005;565:3-8.
3. D'eath RB, Tolkamp BJ, Kyriazakis I, et al. 'Freedom from hunger' and preventing obesity: the animal welfare implications of reducing food quantity or quality. *Animal Behaviour* 2009;77:275-288.
4. AZA. Lion Species Survival Plan: Lion Care Manual. Silver Spring, MD: Association of Zoos & Aquariums, 2012;143.
5. NRC. *Nutrient requirements of dogs and cats*. Washington, D.C.: National Academy Press, 2006.
6. Hendricks WH, Wamberg S. Milk intake of suckling kittens remains relatively constant from one to four weeks of age. *J Nutr* 2000;130:77-82.
7. Rattray PV, Garrett WN, Hinman N, et al. Energy cost of protein and fat deposition in sheep. *J Anim Sci* 1974;38:378-382.
8. Kienzle E. Factorial calculation of nutrient requirements in lactating queens. *J Nutr* 1998;128:2609S-2614S.

9. National Research Council (NRC). *Nutrient requirements of small ruminants: sheep, goats, cervids and new world camelids*. Washington, D.C.: National Academies Press, 2007.
10. Cain BW. Energetics of growth for black-bellied tree ducks. *The Condor* 1976;78:124-128.
11. Votruba SB, Blanc S, Schoeller DA. Pattern and cost of weight gain in previously obese women. *Am J Physiol Endocrinol Metab* 2001;282:E923-E930.
12. NRC. *Nutrient requirements of horses*. 6th Revised ed. Washington, D.C.: National Academy Press, 2007.
13. Allen, ME, Oftedal, OT, Earle, KE, Seidensticker, J, Vilarin, L. Do maintenance energy requirements of felids reflect their feeding strategies? In proc Nutrition Advisory Group, Toronto, CA, May 1, 1995, p. 97-103.

Table 1. Example of estimated requirement differences for Zn and P between 4 horses on varying diets.¹² Note that requirements based on dry matter (DM) intake (e.g. Zn) may underestimate the needs of animals consuming energy dense diets, and requirements based on bodyweight (BW) (e.g. P) may underestimate the needs of animals with high energy requirements.

					Estimated Nutrient Requirements			
Horse	DM intake				Zn, 40 mg/kg DM intake		Zn, scaled for kcal	
	kg BW	kg	kcal/kg	Mcal/d	mg/d	mg/kgBW	mg/kcal	mg/d
A	500	7.5	2500	18.8	300	0.6	0.016	338
B	500	7.5	2000	15.0	300	0.6	0.020	270
C	300	7.5	2000	15.0	300	1.0	0.020	270
D	300	6.0	2500	15.0	240	0.8	0.016	270

Horse	DM intake				P, 28 mg/kg BW		P, scaled for kcal	
	kg BW	kg	kcal/kg	Mcal/d	mg/d	%DM	mg/kcal	mg/d
A	500	7.5	2500	18.8	14000	0.19	0.75	15938
B	500	7.5	2000	15.0	14000	0.19	0.93	12750
C	300	7.5	2000	15.0	8400	0.11	0.56	12750
D	300	6.0	2500	15.0	8400	0.14	0.56	12750

Table 2. Spreadsheet for calculating average kcal/d for each new diet. Energy conversion factors are based on best information available including FWZ quality control analysis, Attwater approximations, manufacturers' information and published data.

0.1 <i>Panthera tigris</i>		Diet per week					
Diet start date	Average kcal/d	Horse muscle meat, g	Beef Meat mix, g	Horse meat mix, g	1/2 shank beef, ea	1/2 shank horse, ea	Rabbit lbs
11/15/2007	5986	200	19728		2		7.5
6/29/2008	5486	180	17754		2		7.5
10/7/2008	4549	180	14028		2		7.5
1/24/2009	4549	180	14028		2		7.5
2/1/2009	4549	180	14028		2		7.5
2/28/2009	4194	162	12630		2		7.5
5/29/2009	3819	162	12630		3		
7/14/2010	4313	162	14592		3		
3/19/2011	5669	162		17874		3	
7/6/2012	5055	162		15636		3	
8/19/2012	4625	162		14070		3	
2/23/2013	5127	162		15900		3	
4/5/2013	5346	162		16698		3	
4/23/2013	5580	162		17550		3	
5/4/2013	6302	162		20184		3	

Table 3. Average daily kcal intake combined with bodyweight (or body condition) data.

Date	Weight, kg	Diet, avg kcal/d	Avg kcal/d between weights	ADG (g/d) between weights
1/17/2008	79.8		4695	0.3
9/4/2008		7512		
9/24/2009	80		7448	92.1
1/9/2010		6469		
1/16/2010	90.5		6155	38.2
1/22/2010		6140		
5/27/2010	95.5		5192	-72.5
7/14/2010		5580		
9/15/2010		4463		
12/20/2010	80.5		4686	65.8
1/13/2011		5067		
1/27/2011	83		5994	75.4

Table 4. Estimated energy requirements for felids.

Species	Maintenance requirement, kcal/d	Cost for gain, kcal/g	Bodyweight, kg	Maintenance requirement, kcal/kgBW ^{0.75}
<i>Felis domesticus</i> ¹	250	1.8 (nursing kittens)	4	90
<i>1.0 Acinonyx jubatis</i>	2879	6.0	60	134
<i>1.0 Panthera onca</i>	3081	6.8	70	127
<i>0.1 Panthera tigris</i>	4894	16.5	90	167
<i>Panthera leo</i> ²	4000-7000		110-200	115-130
<i>Acinonyx jubatis</i> ³			40-60	150-185
<i>Panthera tigris</i> ³			90-200	200-260
<i>Panthera leo</i> ³			100-200	100-150

¹NRC 2006

²AZA Lion Care Manual, 2012

³Allen et al., 1995

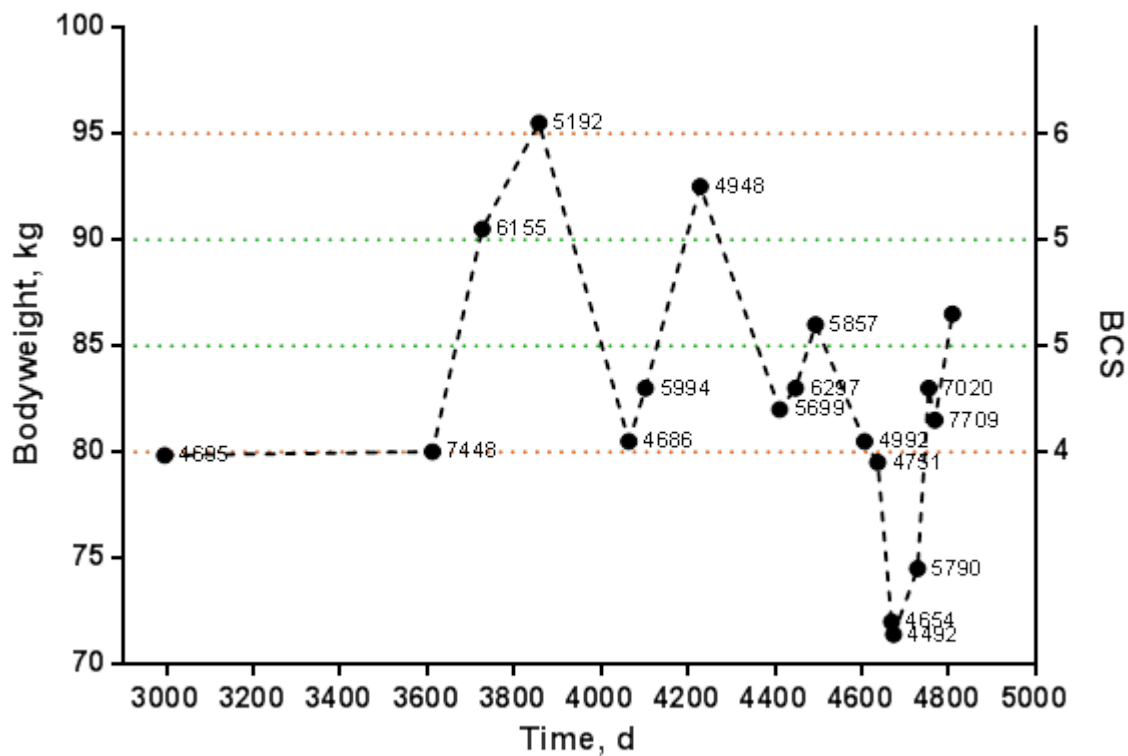


Figure 1. Animal's weights over time plotted with body condition score on 9-point scale. Labels indicate the average kcal/d starting at that time point.

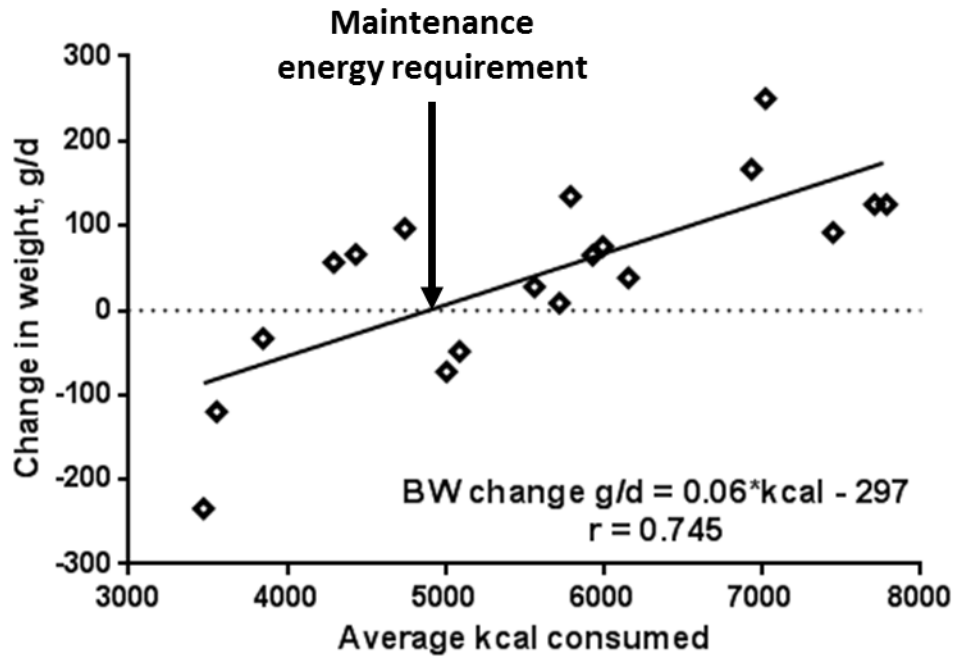


Figure 2. Weight changes compared to average daily kcal intake.