Evaluation and Reformulation of Diets for Captive Aye-Aye *(Daubentonia madagascariensis)*

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The feeding choices of wild aye-aye *(Daubentonia madagascariensis)* have been studied recently and found to include insects, insect larvae, nuts, bark, fungi, and fruits. Proximate analyses, some mineral, and some fat-soluble vitamin analyses of commonly consumed food items have been performed on these choices but there are no published data available which have quantified nutrient intake in captivity in relation to health of these animals. Nutritional problems manifested in an infant aye-aye at Duke University Primate Center (DUPC), resulted in a thorough evaluation of the DUPC diet for 3.4 aye-aye. This evaluation led to a reformulation of the DUPC aye-aye diet and likely contributed to increased reproductive success. The original diet, consisted primarily of vegetables, fruits, and insects, and was deficient in many nutrients. The percent of food consumed versus that offered ranged from 13 to 22%. It was noted that the animals were consuming large quantities of some food items while ignoring other items in the diet. The analysis of Diet 1 led to a reformulated diet (Diet 2) that included a nutritionally complete commercial primate biscuit. The key to consumption of the nutritionally complete diet was its presentation in a manner which reflected natural feeding behaviors. As a result of this new presentation, the DUPC aye- aye began consuming 57-82% of the newly formulated diet and 55-95% of their nutritionally complete primate biscuit. Since consuming the reformulated diet, have lost their "unkempt" appearance and females are now at maximum reproductive capacity.

Key words: Aye-Aye, *Daubentonia madagascariensis,* diet, captivity, nutrition

INTRODUCTION

The feeding ecology of the free-ranging aye-aye *(Daubentonia madagascariensis)* has only recently been studied (E. Sterling, 1993). This research has shown previously held opinions that aye-aye are primarily insectivorous to be in error. Aye-aye should be considered a generalist seed/insect feeder. They have been found to be predominately nocturnal and forages on seeds, nuts, fruits, nectar , insects, insect larvae, and fungus. The method of foraging is peculiar to the species in that it uses its unique incisors to bore through branches and trunks of trees or the husks of nuts and fruit (Gaulin, 1979). Aye-aye then manipulate its elongated third finger to obtain insects and/or the meat of the nut or fruit. (lwano and Iwakawa, 1988) Samples of food items consumed by wild aye-aye have been analyzed for macro-nutrients (E. Sterling, 1993). It is very difficult to quantify nutrient intake of free-ranging primates due to variation in intake rates (Oftedal, 1992). Thus, the relationship between the nutrient intake of wild individuals to the nutrient intake of captive animals is unknown.

A study conducted on food intake of four captive aye-aye at the Jersey Wildlife Preservation Trust (JWPT) over a 10 day period found their diets to be deficient in several nutrients as compared to published nutrient requirements for Old World Primates (Sterling, et al, 1994).

Nutritional problems in a Duke University Primate Center (DUPC) infant aye-aye led to a thorough evaluation of the DUPC diet. This paper describes the various phases of the diet evaluation of the DUPC aye-aye diet, the resultant reformulation of the diet, its acceptance by the DUPC aye-aye, and the resultant reproductive success for the largest captive colony of aye-aye.

METHODS

Average food consumption of seven (3.4) aye-aye housed at DUPC was determined three days in September 1993. Consumption was calculated by determining the quantity (by weight) of food items offered and subtracting the quantity of food remaining at the end of the day. Data were averaged over the days and a computer analysis (Animal Nutritionist software by N-squared Inc, Silverton, OR) was performed to calculate nutrient content of the diet both offered and consumed.

The test subjects were housed and fed in the following groupings; two pair (one mother and suckling young, one adult pair) and four animals housed singly. Data from Diet 1 were collected all 7 aye-aye as they were housed. Diet 2 food consumption and nutrient content data were gathered on only the four individually housed animals.

In total, two diets were evaluated. Diet 1 (1993), was the original diet fed to the aye-aye since their arrival from Madagascar in 1987 and 1991. Food items offered in this diet were predominately fruit. After Diet 1 proved to be deficient, a new diet was formulated (Diet 2) Another intake study was performed in June, 1994 for Diet 2.

The primary difference between the two diets was the inclusion, of a nutritionally complete primate biscuit in Diet 2. The total quantity of Diet 2 fed to each animal was limited to decrease the incidence of the animals consuming only favored food items. Additionally, the nutritionally complete biscuit was soaked in water to a "gruel" consistency and placed in a bamboo section. The bamboo sections were cleaned and sterilized and had pre-drilled holes at various places along the approximately two foot section. The gruel consistency was found to be necessary after a neurological examination which tested the reflexes and developmental progress on one of the aye-aye infants. This examination led to the identification of the fact that neither adult nor young aye-aye can grasp things between their fingers and palms or thumbs, i.e., they can not make a fist. They therefore, could not pick up the commercial biscuits. Bamboo was used when it was found that the aye-aye would not eat the gruel out of an open stainless steel pan, but they readily ate it when the gruel was presented to them inside a section of bamboo.

RESULTS

The mean consumption of Diet 1 by DUPC aye-aye is shown in Table 1. The percent of presented food that was consumed ranged from 13 to 22%. Thus the aye-aye were eating only a small quantity of food being offered to them. Also it was noted that, in general, the aye-aye were consuming large quantities of some food items while totally ignoring other items in the diet. The test animals' diet consisted of 15% fruit, 51% vegetables, 16% starchy vegetables, 2% insects, and 16% miscellaneous. The mean consumption of food was 14% of body mass on an as fed basis and 2.3% on a dry matter basis for Diet 1.

TABLE 1. Mean Consumption of Diet 1 and Diet 2 by DUPC aye-aye

DIET 1. CONSUMED (WET WEIGHT BASIS in grams)

Food group*	consumed mean	consumed range	mean percent consumed
Veggie	192	58-315	50
Starchy	58	0-112	5
Fruit	55	22-113	25
Insects	7	0-15	12
Misc	58	15-125	17
Totals	371	145-518	17

*Food group: Veggie was avocado and cucumber. Starch. Fruit was melon, orange, and apple. Insects were mealworms. Misc. was egg, sugar cane and coconut. At that point, no nutritionally complete chow was fed. Within a food group, items varied.

DIET 2. CONSUMED (WET WEIGHT BASIS in grams)

Food group*	consumed mean	consumed range	mean percent consumed
Gruel	105	84-138	76
Veggie	38	23-58	58
Starchy	90	59-127	61
Fruit	150	93-195	67
Insects	3	3	100
Misc	82	65-116	64
Totals	486	412-566	68

*Food group: Gruel was a mixture of water and Hi-protein monkey chow (Purina Mills). Veggie was cucumber. Starchy was sweet potato and corn. Fruit was melon, peach, orange, apple, and plum. Insects were mealworms. Misc. was egg and coconut. Within a food group, items varied.

Diet 2 produced considerably less wastage as the aye-aye consumed an average of 68% of their diet (range 57-82%) and more importantly, individuals consumed between 55% and 95% of their gruel (commercial primate biscuit mixed with water). Additionally, it should be noted that animals actually consumed more food when fed Diet 2, even though less food was offered, i.e.,

they ate 19% of body mass (as fed basis), 3.5% (dry matter basis) for Diet 2 as compared to 14% of body mass (as fed basis) and 2.3% (dry matter basis) for Diet 1. When offered Diet 2 the aye-aye chose 31% fruit, 10% vegetables, 18% starchy vegetables, 1% insects, 17% miscellaneous and 23% gruel.

The animals consumed an average of 238 kcal/day (91 kcal/kg body mass) with Diet 1 compared to 396 kcal/day (152 kcal/kg body mass) with Diet 2. Body mass did not change significantly over the time the two diets were fed (mean = 2.61 kg for adults).

Calculations of the nutrient content when animals consumed Diet 1 (Table 2.) demonstrated that there were apparent deficiencies in various nutrients when compared to Diet 2 and when compared to nutrient requirements of Old World Primates (NRC, 1978).

TABLE 2: Comparison of nutrient intake (dry matter basis) for both diets

	DIET 1		DIET 2		
NUTRIENT	MEAN	RANGE	MEAN	RANGE	REQ*
Dry matter%**	16.5	7-23	18.5	11-25	-
Kcal/g	3.9	3.6-4.6	4.4	3.9-5	-
Protein, %	11	10-13	18	14-21	17-28
Fat %	24	14-41	27	21-39	-
Fiber %	6	2-10	4	3-7	-
Lino acid %	1.1	.3-3	0.6	.2-1.3	1
Vit A IU/g	0	0	57	29-86	13.9
Vit D IU/g	0	0	4.9	2.1-7	2.2
Vit E mg/kg	11	8-16	475	221-711	55.6
B1, mg/kg	4	2.4-5	22.5	12-23	-
B2 mg/kg	3	2.2-5.4	26	12-38	5.56
Niacin mg/kg	34	28-38	278	161-402	56
B6 mg/kg	5	4.4-6.4	28	15-40	2.8
Folacin mg/kg	1.6	1.3-2.2	6	3.4-8.4	.22
B12 mg/kg	0	0	.2	.04-.1	-
PantAcid mg/kg	23	16-39	143	79-215	17
Biotin mg/kg	0	0	113	51-172	.11
Vit C mg/kg	824	424-1378	1852	1044-2744	111
C %	.11	.03-.28	.37	.19-.6	.55
P %	.26	.13-.35	.61	.34-.72	.44
Mg %	.1	.08-.1	.25	.16-.26	.17
Fe mg/kg	37	29-52	304	152-452	200
Zn mg/kg	21	13-26	200	99-292	11
Cu mg/kg	8	6-14	30	17-44	-

*Requirement for Old World primates all stages, (NRC, 1978). Some suggest that the protein requirement for New World primates (28%) is overestimated.
**Dry matter is expressed on an as fed basis.
"-" means that there is no NRC published requirement for this nutrient. However there may be a requirement at some level.

DISCUSSION

Food Offered Versus Consumed

The DUPC aye-aye routinely consumed only 13 to 22% of the food (Die presented to them. It is quite apparent that the animals were sorting their diet considerably. The result being that they were able to consume only their favored items, leaving the rest. Because there were able to become satiated on only a few items, they were not eating a nutritionally balanced diet and considerable food was being wasted.

A captive animal is, by definition, artificially restricted with respect to diet choices, regardless the effort to replicate the natural diet. If an animal is offered an artificially limited diet which is a similar in nutrients and possibly even dietary items to the natural diet and this diet meets the actual physiological nutrient requirements of the animals, it can considered to be an adequate diet. The effect of sorting however, can turn an adequately formulated diet into an inadequate diet. It is what the animals consume not what they are offered that contributes to nutrients utilized. It then becomes vital to encourage the animal to consume its nutrient complete diet (in total (or near total).

Thus to encourage more complete consumption of a nutritionally complete diet individual food choices were limited by limiting the total quantity of food offered (Diet 2). To increase the nutrients in the aye-aye diet, a commercial primate biscuit was added. The result was a remarkable increase in consumption of the total diet and all diet items. Results show that not only did total food consumption jump from 371 to 486 grams per animal per day but also kcal intake increased from 90 kcal/kg body mass to 152 kcal/kg body mass. This occurred without a change in overall body mass.

Consumption of the captive aye-aye diet in the JWPT study (Sterling, et al., 1994) averaged 300 grams daily compared to 371 and 486 for DUPC Diets 1 and 2, respectively. This may be due in part to the composition and energy density of the diets. However the energy and protein density was higher in diets 1 and 2. (See Nutrient intake section.)

Nutrient requirements

Nutrient requirements of aye-aye have not been determined. The nearest animals taxonomically for which nutrient requirements have been determined are classified as Old World primates (NRC, 1978). These requirements may not accurately reflect aye-aye requirements but may serve as an adequate benchmark. When examining the diets of wild aye-aye, seeds and fungus as well as insect larvae were found to contribute substantially to the nutrient composition of the diet (Sterlir, 1993). *Canarium* seed, a staple in the diet, was found to be 16.5% protein and 60% fat. Insect larvae contributed substantial protein and fat to the diet (31 to 57% protein; 33-44% fat). Fungus which was low protein (4%) and high fat (40%), also contained the highest reported quantities of calcium (0.2%) with a 4.2 Ca:P ratio. Wild aye-aye also consumed nectar and it is possible that there are as yet undocumented or incidental ingestion of other sources of nutrients. For example, gums and saps which aye-aye may ingest while boring through branches for larvae may be a source of calcium (Bearder and Martin, 1980). Additionally, if aye-aye moving about in the daylight this activity may provide a source vitamin D from sunlight.

Nutrient intake

When compared to nutrient requirements for Old World primates the DUPC Diet 1 was clearly deficient in many nutrients. The nutrients that appeared low included protein and possibly linoleic acid, vitamins A, D, E, thiamin, niacin and biotin as well as the minerals: calcium, phosphorous, iron and possibly magnesium (Table 2). There also was an inverse calcium to phosphorous ratio and Diet 1 was considered high fat. Most of the fat originated from coconut, avocado, mealworms, and egg. Even though there was little vitamin A present, there were carotenoids in the diet which may be converted to active vitamin A (Olson, 1984) but this has not been studied in the aye- aye. These nutritional results are consistent with the results from analysis of diets fed at JWPT (Sterling, 1994).

The requirement for vitamin D for Old World primates may be supplied in either form: D2 (available in plant sources) and D3 (available in animal sources) (Norman and Miller, 1984). But the source required for aye-aye is not known. Also, in many animals, the skin can synthesize vitamin D with exposure to specific ultra-violet light rays. However the aye-aye are housed inside with no exposure to sunlight.

The discovery that the DUPC Diet 1 was not nutritionally adequate led to the formulation of Diet 2. This new diet was designed to include a commercially available primate biscuit and the total diet offered was limited to encourage consumption of every diet item. This diet can be considered a moderate protein, high fat diet. However this is not unlike many of the food items consumed in the wild (Sterling, 1993). Compared to the probable nutritional requirements of aye-aye, consumption of Diet 2 meets or exceeds requirements for most nutrients examined. Two nutrients which remain problematic are Ca and P, especially the CA:P ratio which should be nearer 1: 1 to 2: 1 (NRC, 1978).

A comparison of the JWPT and DUPC aye-aye diets shows that the energy density of the JWPT diet was 2.3 kcal/g compared to 3.9 and 4.4 kcal/g of Diets 1 and 2, respectively. Energy density for wild aye-aye diets was reported to be from 4.0 -4.2 kcal/g during four warm weather seasons but 1.7 kcal/g during one cold weather season (Sterling 1993). These values could have been underestimated since energy from nectar consumed was not quantified. Likewise, the protein level of the JWPT diets was 6.2 % compared to 11% and 18% for Diets 1 and 2, respectively. Thus it appears that the more energy and protein dense the diet, the more the animals consumed. The protein content of the wild aye-aye diets was calculated to be 10.8% -15.1% (Sterling, 1993) which compared more favorably with DUPC Diets 1 and 2.

Given that the body mass remained similar over the course of the year, the two diets (1 and 2) were fed, it may be that the additional energy and protein was utilized by the animals for activity, hair coat growth, and reproduction. All four of the DUPC adult females have had at lease one surviving offspring.

Diet success

It should be noted that often animals may be borderline or actually deficient in nutrients and show no actual outward clinical signs unless stressed as in rapid growth spurts or pregnancy and

lactation. Thus, an animal which exists in poor nutrient status demonstrates the effects are demonstrated in slow growth, poor hair coat, and limited reproductive success. At DUPC, prior to 1993, the aye-aye were reported to have "poor" hair coats, additionally, while there was some reproduction (two births), one infant developed a severe case of rickets and was subsequently supplemented with all nutrients, including vitamin D. After the adults were fed Diet 2, hair coat improved and the aye-aye have produced 3 additional surviving offspring. One animal who was thought to be post-reproductive with a poor hair coat, began cycling and produced offspring after being fed Diet 2. Her hair coat became sleek and more dense. Much of the aye-aye reproductive success has been attributed to recent nutrition work.

CONCLUSIONS

Exact nutrient requirements of the aye-aye are unknown. Estimation of probable requirements can be taken from data on primates for which nutrient requirements have been determined as well as data on wild individuals and captive collections. Diets should be evaluated based on nutrient status of the animals taken from measures of health, reproduction and if possible, biochemical parameters. It has been shown that aye-aye can tolerate a high energy, high fat diet (which may be similar to that obtained in the wild). Protein requirements are still in question but a successful diet formulated at DUPC has been shown to provide levels reaching near the Old World primate requirements. Requirements for vitamins and minerals continue to remain illusive however targeting the Old World primate requirements should provide adequate levels in captive diets.

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